Guidelines for the Seismic Retrofit of Existing Schools and Design of New Schools in the Republic of Armenia

THE GOVERNMENT OF
THE REPUBLIC OF ARMENIA

ATC
Applied Technology Council

WORLD BANK GROUP
Social, Urban, Rural & Resilience

GFDRR
Global Facility for Disaster Reduction and Recovery

Guidelines for the Seismic Retrofit of Existing Schools and Design of New Schools in the Republic of Armenia

Prepared for

THE GOVERNMENT OF THE REPUBLIC OF ARMENIA

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Preface

Armenia is a country with a history of large and devastating earthquakes. Many schools were built prior to the consideration of earthquake effects, some were built per USSR building codes that specified significantly underestimated seismic hazard levels, and most include structural characteristics that are not expected to perform adequately in a major earthquake. Recognizing the need to take action, the Government of Armenia made seismic safety of schools a national priority and launched the Safe School Improvement Program (SSIP) in 2015. This Program represents Armenia's first effort to address the seismic vulnerability of Armenia's school building stock at scale. The current target of the Program is to improve the safety of 423 schools.

While there is political commitment to address earthquake risk in the education sector, significant technical challenges remain, including the lack of a uniform approach to retrofitting existing school buildings and designing new school buildings. In order to overcome this challenge and to achieve a uniform level of safety and performance improvement across the inventory of school buildings, the Government of Armenia identified the need to develop a set of guidelines that includes planning, design, construction, and maintenance procedures associated with the retrofit of existing school buildings and the construction of new school buildings.

Guidelines for the Seismic Retrofit of Existing Schools and Design of New Schools in the Republic of Armenia has been developed with the support of the Global Facility for Disaster Reduction and Recovery's (GFDRR) Global Program for Safer Schools (GPSS). This Program aims to support disaster prone countries to address disaster risk in the education sector through a comprehensive package of technical assistance and advisory services. For the development of these *Guidelines*, the Program partnered with Applied Technology Council (ATC). Since 1973, ATC has been at the forefront of developing and promoting user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment. Over its history of operation, ATC has developed more than 150 major reports and engineering guidelines that have served to define seismic engineering design practice in the United States, including seismic design of new buildings, seismic evaluation and retrofit of existing buildings, and evaluation and repair of earthquake-damaged buildings; many have become de facto international standards.

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This Project was developed under the leadership of Vica Rosario Bogaerts (Task Team Leader). The complete World Bank team included: Tafadzwa Irvine Dube, Maryia Markhvida, and Nora Mirzoyan.

Leading Authors and Team

The World Bank gratefully acknowledges ATC as the leading author of these *Guidelines*. The Project Technical Committee (PTC), responsible for the technical development of these *Guidelines*, was led by Jon Heintz (ATC, Project Executive) and Veronica Cedillos (ATC, Project Manager). The PTC, consisting of Peter Yanev (Chair; Yanev Associates), Garry Myers (MKC Global Protection), Garik Chilingarian (LGS Group), Zaven Khlghatyan (Earthquake Engineering Center), and Andrew Yanev (Yanev Associates), researched and assembled the information contained herein and supported and assisted during in-country missions. Engineering design services were provided by Rafael Alaluf (EQRM International). Finally, Carrie Perna (ATC) was responsible for the report production services.

Reviewers

The Project Advisory Panel (PAP) provided technical review, advice, and consultation at key developmental stages of the work. The PAP included: Victoria Arbitrio (Gilsanz Murray Steficek; ATC Board Representative), Tigran Dadayan (National University of Architecture and Construction of Armenia), Armen Der Kiureghian (American University of Armenia and University of California at Berkeley), William Holmes (Rutherford & Chekene), Ryan Kersting (Buehler & Buehler Structural Engineers), Eduard Khachiyan (National University of Architecture and Construction of Armenia), Temur Margaryan (National University of Architecture and Construction of Armenia), Gurgen Namalyan (Earthquake Engineering Center), and Loring Wyllie (Degenkolb Engineers). Eduardo Miranda (Stanford University) served as a consultant to the World Bank, and provided an independent technical review of the recommendations contained herein.

National Government Collaborators

The Government of Armenia, through the Committee of Urban Development (CoUD) and the Armenian Territorial Development Fund (ATDF), helped the team to develop these *Guidelines*. The following officials offered fundamental contributions during the technical workshops related to the development of the *Guidelines*: Agasi Hovsepyan (CoUD), and Hayk Galstyan and Ruben Terzyan (ATDF).

Collaborators

Organizations such as the Asian Development Bank (ADB), United National Children's Fund (UNICEF), and United Nations Development Program (UNDP) aided in the collection of data and actively participated in the review of these *Guidelines*. The team is especially grateful to Gohar Mousaelyan (ADB), Tigran Tovmasyan (UNICEF), Diana Harutyunyan and Vahram Jalalyan (UNDP), and Vazgen Sedrakyan (Tym Tym Flynn Architects, Yerevan Branch).

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Finally, special thanks to the Global Facility for Disaster Reduction and Recovery (GFDRR) for funding the development of these *Guidelines*.

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Chapter 1
Introduction

These *Guidelines* were developed through a World Bank Technical Assistance project as part of the Global Facility for Disaster Reduction and Recovery's (GFDRR) Global Program for Safer Schools (GPSS). The majority of existing school buildings in Armenia were constructed during the Soviet Era. Many were built prior to the consideration of earthquake effects, some were built per the Union of Soviet Socialist Republics (USSR) building codes that specified significantly underestimated seismic hazard levels, and most include structural characteristics that are not expected to perform adequately in a major earthquake.

The intent of these *Guidelines* is to provide practical guidance for planning, design, construction, and maintenance associated with the retrofit of existing school buildings, and the construction of new school buildings, to achieve a uniform level of safety and performance improvement across the inventory of school buildings in the Republic of Armenia.

1.1 Scope of the *Guidelines*

These *Guidelines* provide: (1) guidance on the seismic retrofit of existing school buildings; (2) guidance on the seismic design of new school buildings; (3) conceptual design examples for retrofit of typical existing school buildings; and (4) a conceptual structural design example for typical new school buildings. In providing conceptual design examples for typical buildings, these *Guidelines* do not provide prescriptive engineering solutions for any one specific building. As a result, implementation of these *Guidelines* requires the involvement of engineers that are knowledgeable in seismic design practice. The applicability of the recommendations contained within these *Guidelines* must be specifically evaluated for each individual school building and the conditions that are present at each existing or new school site.

The inventory of public schools in Armenia has been categorized into five structural typologies in the report, *Preventing Disaster Losses and Reducing Vulnerability of Children in Armenia Project: Summary Report* (EEC et al., 2015). These typologies are described in detail in Chapter 2. Some typologies have been used more frequently than others, and not all typologies are considered suitable for retrofit. As a result, these *Guidelines* do not explicitly address all structural typologies in detail. The focus of these *Guidelines* has been limited to the three most common typologies that are also considered the most reasonable candidates for retrofit.

Current Armenian building codes and construction norms include provisions for seismic design, and specify explicit seismic performance objectives for schools. As a result, current Armenian codes and construction norms are used as a starting point for minimum requirements for design and construction. These *Guidelines* have been scoped to provide supplemental requirements deemed necessary to meet the specified performance objectives for schools, and to raise minimum requirements to levels consistent with international standards and best practices for earthquake-resistant design in regions of high seismicity around the world.

1.2 Relationship to Other Programs

Development of these *Guidelines* was initiated by the World Bank in support of the Government of Armenia's School Safety Improvement Program (SSIP), which was approved as Resolution N 797-N in 2015 (Republic of Armenia, 2015). The target of the SSIP is the large inventory of seismically vulnerable school buildings located throughout Armenia. The goal of the program is to improve the seismic safety of 377 schools, with approximately $620 million in investments and support from international development partners and donors.

With assistance from the Asian Development Bank (ADB), the Government of Armenia has initiated work to select school buildings for retrofit, and commission retrofit designs under the SSIP. Guidance for retrofit of existing school buildings and design of new school buildings under this program is currently outlined in the following ADB publications: *Supplemental Requirements for Strengthening of Existing School Buildings* (ADB, 2016a), and *Supplemental Requirements for New Construction* (ADB, 2016b).

In parallel with the effort to strengthen and renovate existing schools, a program was initiated to develop a model for new school construction in Armenia that is based on community needs, current demographics, and modern educational concepts. The United Nations Development Programme (UNDP) is developing a standard, modular design for new school buildings, with a goal of improving energy efficiency. Design assistance is being provided by international partners, but seismic design of new buildings under this program is primarily based on current Armenian building code requirements.

These *Guidelines* are intended to provide practical recommendations for seismic retrofit of existing school buildings and seismic design of new school buildings that can be used to inform all school programs in the Republic of Armenia, including those conducted under the SSIP and other efforts. To facilitate use in ongoing school programs, these *Guidelines* have been developed with explicit consideration of the types of school buildings currently being targeted for retrofit by the Asian Development Bank, as well as the modular construction of new model school buildings currently being developed under the United Nations Development Programme.

1.3 Methodology and Approach

A multi-national (U.S. and Armenian) team of experts was assembled to review available information, including codes, standards, guidelines, and available documentation on the design and construction of new and existing school buildings in Armenia. Existing school buildings of all structural typologies, at school sites located around the country, were investigated to observe existing conditions and confirm the nature of the existing construction.

To facilitate technical implementation, and improve overall quality of the resulting design and construction work, criteria in these *Guidelines* have been developed using Armenian codes and construction norms as a starting point. Conceptual design and retrofit solutions have been developed using engineering and construction technologies that are known to be widely used and readily available in

Armenia. Where considered necessary, code requirements and design recommendations have been supplemented with international standards and best practices for earthquake-resistant design. Many advanced engineering technologies and high-performing structural systems are in existence around the world, and many of these could be considered for improving the seismic performance of school buildings in Armenia. However, only those technologies and systems that are generally consistent with widespread Armenian design and construction practices, which can be implemented at scale across a large inventory of buildings, have been recommended for use in these *Guidelines*.

1.4 Organization and Content

These *Guidelines* provide general guidance supplementing current Armenian codes and standards related to seismic retrofit of existing school buildings and seismic design of new school buildings. The organization and content of these *Guidelines* is as follows:

Chapter 2 summarizes available information, codes, construction norms, and existing conditions for school buildings in Armenia.

Chapter 3 describes Armenian earthquake hazard levels and performance levels, and prescribes recommended levels for design of schools.

Chapter 4 outlines the recommended procedure for evaluation and retrofit of existing school buildings, and describes conceptual retrofit solutions for the most common structural typologies.

Chapter 5 outlines the recommended procedure for design of new school buildings, and describes a conceptual structural design solution for new model school construction.

Chapter 6 provides recommendations for seismic design and installation of seismic restraints for nonstructural systems and components in school buildings.

Chapter 7 provides implementation recommendations related to design and construction quality assurance and ongoing maintenance of school facilities.

Appendix A provides the data collection and evaluation form for use in selecting buildings for retrofit.

Appendix B provides structural plans and details for conceptual seismic retrofit of typical Typology A classroom and gym buildings.

Appendix C provides structural plans and details for conceptual seismic retrofit of typical Typology D-1 classroom and gym buildings.

Appendix D provides structural plans and details for conceptual seismic retrofit of typical Typology D-2 classroom and gym buildings.

Appendix E provides structural plans and details for conceptual seismic design of new school buildings.

Chapter 2
Building Codes, Construction Norms, and Existing Conditions

This chapter summarizes available information, including building codes, construction norms, standards, guidelines, and available documentation on the design and construction of new and existing school buildings in Armenia.

2.1 Armenian Building Codes, Construction Norms, and Material Design Standards

During the Soviet Era prior to the 1988 Spitak earthquake, buildings and structures in Armenia were designed and constructed in accordance with the USSR codes and regulations, such as SNIP II-7-81, *Construction in Seismic Areas* (SNIP, 1982). The first Armenian seismic code was issued in 1994, and the first construction norms for rehabilitation, restoration, and reinforcement of buildings were issued in 2000.

Current structural design of buildings in Armenia is governed by the Republic of Armenia Building Code, RABC II-6.02-2006, *Earthquake Resistant Construction Design Codes* (Ministry of Urban Development, 2006), published in 2006 and unofficially translated into English. This code was first published in 1994 and the current version is the second edition. The Armenian building code addresses seismic zoning in Armenia, soil classification, earthquake loading, and analysis and design principles for residential, public, and industrial buildings and structures. It specifies soil factors, importance factors, seismic loads, permissible levels of damage, and height limits on certain types of buildings, including schools. All types of structures are addressed, including masonry, precast, and cast-in-place concrete buildings. The code also addresses the restoration and strengthening of buildings and structures.

The Armenian building code is supplemented by Construction Norms of the Republic of Armenia, CNRA 20-06-2014, *Reconstruction, Rehabilitation and Reinforcement of Buildings and Structures: Key Provisions* (Ministry of Urban Development, 2014). CNRA 20-06-2014 specifies an approach for assessing the condition of existing buildings, and defines different levels for repair or seismic improvement, as follows:

- **Reinforcement** – construction to increase a building's seismic resistance to comply with current codes or normative requirements. This definition is equivalent to seismic strengthening.
- **Rehabilitation** – construction to restore a building's seismic resistance to its original or pre-existing condition. This definition is equivalent to restoration.
- **Reconstruction** – construction to modernize a building for new occupancy or use.

- **Repair** – construction to rehabilitate or replace damaged or deteriorated components in a building.

CNRA 20-06-2014 requires different levels of repair or improvement based on assessment criteria including occupancy, use, and the condition of the building. Important criteria affecting schools in Armenia include:

- Degree of damage in the building or structure.
- Degree of non-compliance with the requirements of existing norms.
- Behavior of similar buildings (typologies) in recent earthquakes.
- Physical deterioration and aging of the building and structure.
- Nature and extent of rehabilitation measures carried out after prior damage.

The Armenian construction norms specify that seismic strengthening of schools shall use a coefficient of seismic preparedness (referred to as K_{cb} in CNRA 20-06-2014 and as K_{SP} in RABC II-6.02-2006) equal to 1.0, which means that retrofitted schools must meet the current requirements for new schools. They also specify that reinforcement or reconstruction designs should be subject to review.

The term "retrofit" used in these *Guidelines* is most closely aligned with the term "reinforcement" in CNRA 20-06-2014, meaning that retrofit design and construction recommendations in these *Guidelines* are intended to increase the seismic resistance of an existing school building to levels that are consistent with current requirements and performance expectations in Armenian building codes and construction norms.

Design and construction of concrete and reinforced concrete structures is still governed by Russian standards. The current material design standard for reinforced concrete is SNIP 2.03.01-84*, *Concrete and Reinforced Concrete Structures* (SNIP, 1984).

2.2 Prior Studies and Reports

Prior studies on existing Armenian school buildings, building regulations, and design, retrofit and construction practices are available in the literature. The following reports contain relevant information that contributed to the content of these *Guidelines*:

- *Preventing Disaster Losses and Reducing Vulnerability of Children in Armenia* (EEC et al., 2015). This project was conducted by the Armenian Earthquake Engineering Center (EEC) of the Western Survey for Seismic Protection (WSSP) State Non-Commission Organization (SNCO) under the Ministry of Emergency Situations (MES) in Armenia, with the assistance of the United Nations International Children's Emergency Fund (UNICEF). Data on about 1,400 school campuses in the country were collected. The report summarizes findings from a detailed review of 20 typical existing school designs, and developed the fundamental characterization of school buildings divided into five structural typologies (A, B, C, D-1, and D-2) used in these *Guidelines*.
- *Armenia Mission Report* (The World Bank, 2016). This project was conducted by Ove Arup & Partners International Ltd for The World Bank under the Global Program for Safer Schools, Global

Facility for Disaster Reduction and Recovery. The report describes important aspects of Armenian building practices, summarizes in the shortcomings in Armenian norms, and provides recommendations for improving design and construction of schools in Armenia.

- *Seismic/Structural Engineering Evaluation of Strengthened Residential Buildings Damaged in the 1988 Earthquake Zone* (Wyllie, 1999). This report outlines typical seismic retrofit schemes implemented on stone masonry residential structures in the areas impacted by the 1988 Spitak earthquake. Although this report highlights schemes for residential construction, some of these same practices can be extended to stone masonry school buildings of similar construction.
- *Design Guideline for New and Strengthened School Buildings, School Designs: Supplemental Requirements for Strengthening of Existing School Buildings* (ADB, 2016a). This report was prepared by Yanev Associates, LLC for the Asian Development Bank. It provides guidance on hazard level, system selection, design requirements, peer review, and construction inspection for seismic retrofit of existing school buildings.
- *Design Guideline for Reconstruction of School Buildings, School Designs: Supplemental Requirements for New Construction* (ADB, 2016b). This report was prepared by Yanev Associates, LLC for the Asian Development Bank. It provides guidance on hazard level, system selection, design requirements, peer review, and construction inspection for design of new school buildings.

2.3 Typical Armenian Design and Construction Practices

Approximately 90% of existing schools in Armenia were constructed prior to the implementation of an Armenian building code, and about 30% were constructed prior to the introduction of earthquake considerations into the 1962 USSR codes (The World Bank, 2016). Prior to 1960, Armenian construction practices utilized bearing walls of unreinforced stone masonry. During the 1960s, precast concrete systems (frames, floors, roofs, and wall panels) were combined with the use of unreinforced masonry (tufa, stone, and formed block) as interior and exterior bearing and non-bearing walls. Beam-to-column connections in precast frames were made using brittle welded splices, and precast floor and roof systems lacked a cast-in-place concrete topping slab for diaphragm continuity.

Many construction techniques, namely the precast concrete systems, were based on practices exported from Moscow, with modifications by local designers. Site adaptation was made locally, based upon site conditions and student population. At the time, there was limited knowledge of seismic design principles, such as the need for ductile detailing and the ability for structures to yield without sudden fracture. Once the structural design was completed, local practice was to turn the design over to a construction company to build. The local engineer was typically not involved from this point forward, and little or no construction inspection was performed. This practice contributed significantly to structural deficiencies and increased earthquake risk, making school buildings of this vintage particularly vulnerable.

Since the 1990s, design and construction of commercial and institutional buildings, including schools, utilizes cast-in-place reinforced concrete frames with floor and roof systems including both precast and cast-in-place concrete (The World Bank, 2016). Low-rise and mid-rise buildings rely on masonry infill for exterior closure walls. A new gymnasium building with cast-in-place concrete frames and reinforced masonry infill walls is shown in Figure 2-1. Special detailing and connections between the masonry infill and the surrounding frame are required, but can be missing or non-existent. Interior partitions commonly consist of precast panels or blocks with minimal reinforcement sandwiched between plaster finishes. Lightweight interior partitions, including the use of steel studs and gypsum wallboard, can be found in modern commercial buildings. Construction inspection and quality control of materials, in general, is not consistent with international standards and best practices, and could be a contributing factor to poor performance of Armenian buildings in future earthquakes.

Figure 2-1 Cast-in-place reinforced concrete frame and masonry infill for a new gymnasium building under construction in Yerevan in 2016.

Armenia does not have an active structural steel fabrication industry. Most steel is imported from Russia or Ukraine. Consequently, structural steel is rarely used for structural purposes aside from miscellaneous metal, such as stair stringers. Steel reinforcing for reinforced concrete construction is used, and is readily available in Armenia.

Shotcrete is a method of applying concrete onto a surface at high velocity through a pressurized hose. Internationally, shotcrete procedures have existed for more than a hundred years. The ability to apply concrete as shotcrete exists in Armenia, but the technology appears to differ from international capabilities in that the shotcrete layers (or lifts) are limited in thickness to no more than a few centimeters at a time.

Modern, innovative technologies are available for seismic design and retrofit in Armenia, such as base isolation and the use of damping devices. These technologies rely on a change in building period or increase in structural damping to control response in an earthquake and reduce demands on the structure. They are used internationally on high-value or important structures. They could be considered for improving the seismic performance of school buildings in Armenia, but advanced engineering technologies and high-performing structural systems are not equally applicable in all situations, and should not be used to allow the continued use of nonconforming structural and earthquake systems. Generally, these technologies are more expensive to implement and more difficult to implement properly, because they require advanced engineering for proper application, utilize imported materials and labor, and require significant ongoing maintenance to function properly. This makes use of innovative technologies difficult for large scale application to the inventory of school buildings in Armenia.

2.4 Existing School Building Typologies

The inventory of public schools in Armenia can be categorized by date of construction, type of construction, structural system, materials and finishes, and number of stories. The classifications used in these *Guidelines* were introduced in the report, *Preventing Disaster Losses and Reducing Vulnerability of Children in Armenia Project: Summary Report* (EEC et al., 2015). The five structural typologies (A, B, C, D-1, and D-2) are described in Table 2-1.

Table 2-1 Existing School Typologies in these *Guidelines* (from EEC et al., 2015)

Typology	*Description of Structural System*	*Date of Construction*	*No. of Stories*	*Coverage in these Guidelines*
A	Complex bearing walls of unreinforced tufa or stone. Precast concrete floor and roof systems. Pre-1960 construction can include timber floor and roof framing.	1930-1960 and post-1960s	1-4	Conceptual retrofit provided (1-3 stories; post-1960s)
B	Exterior bearing walls, interior precast or monolithic concrete frames. Precast concrete floor and roof systems.	1960-1970	1-3	Not explicitly addressed
C	Exterior precast concrete frames, interior precast bearing walls. Precast concrete floor and roof systems.	1960-1970	1-3	Not explicitly addressed
D-1	Distributed precast concrete frame with precast floor, roof, and wall panels. Newer construction can include steel truss roof framing.	1970-1988	1-2	Conceptual retrofit provided
D-2	Distributed precast concrete frame with precast floor, roof, and wall panels. Newer construction can include steel truss roof framing.	1970-1988	3-4	Conceptual retrofit provided (3 stories)

Typology A school buildings consist of exterior and interior complex stone and unreinforced masonry bearing walls with precast concrete floor and roof systems. Some timber floor and roof framing was used on earlier versions of this typology (pre-1960s). Many of the buildings have full or partial basements surrounded by unreinforced stone masonry walls founded on concrete or stone rubble strip footings. There is little or no connectivity between horizontal and vertical structural members and systems. Typical interior non-bearing partitions consist of thin (typically 5-7 cm), segmented, and unreinforced hollow precast concrete panels (pemza block) with plaster finishes on two sides. Typology A buildings represent nearly 60% of all school buildings in Armenia.

Typology B school buildings possess many of the same characteristics as Typology A buildings, including exterior unreinforced masonry bearing walls and precast concrete floor and roof systems. In Typology B buildings, interior bearing walls are replaced with precast or cast-in-place concrete beam-column frame systems and masonry infill walls. Foundations are typically concrete or stone rubble strip footings beneath the walls and isolated footings under the columns. Typical interior non-bearing partitions consist of pemza block with plaster finishes. Typology B buildings make up a very small percentage (approximately 1%) of all school buildings in Armenia.

Typology C school buildings consist of exterior precast concrete beam-column frames and interior precast concrete bearing walls with precast concrete floor and roof systems. In some cases, unreinforced masonry bearing walls have been used instead of precast bearing walls. Many of the buildings have full or partial basements surrounded by unreinforced stone masonry walls founded on concrete or stone rubble strip footings. Typical interior non-bearing partitions consist of pemza block with plaster finishes. With extremely weak precast frames (columns are typically 20 cm x 20 cm), Typology C buildings have been determined to be a poor and difficult candidate for retrofit (Republic of Armenia, 2015). Typology C buildings make up a small percentage (less than 3%) of all school buildings in Armenia.

Typology D-1 school buildings are two stories or less in height, consisting of distributed precast concrete beam-column frames, precast floor and roof systems, and exterior precast wall panels with or without masonry veneer. Some variants include steel truss roof framing with metal deck roofing. Foundations are typically isolated footings at columns. Typical interior non-bearing partitions consist of pemza block with plaster finishes. Precast frame components are connected by short, welded reinforcing bar extensions and formed shear keys for transfer of tension and shear forces in resisting gravity and seismic loads. Exterior wall panels are connected to columns with bolted and welded connections. Construction quality included poor workmanship and little or no quality control. Typology D-1 was the predominant type of construction for school buildings in the period leading up to the 1988 Spitak earthquake (1970-1988), and represents approximately 25% of all school buildings in Armenia.

Typology D-2 school buildings are three- and four-story variations of Typology D-1 buildings with distributed precast concrete beam-column frames developed for correspondingly larger gravity and seismic loads. Precast floor and roof systems, exterior precast wall panels, and typical interior non-bearing partitions are similar to Typology D-1 buildings. RABC II-6.02-2006 limits new school buildings to three stories or less, so four-story Typology D-2 buildings are not currently permitted. Typology D-2 buildings represent approximately 5% of all school buildings in Armenia. Typology D-1 and D-2 buildings at a school site in Yerevan are shown in Figure 2-2.

Each school site consists of at least one building, but many include multiple buildings. Generally, each campus is constructed using one structural typology, but there are often several buildings configured as wings of a larger school complex, as illustrated in Figure 2-3. Individual buildings are connected by corridors, stairs, or other structures, separated by anti-seismic joints (gaps in the structural system). Many campuses contain a gymnasium or auditorium as an independent structure or as part of one of the buildings. Gymnasiums and auditoriums are non-typical, long-span structures with tall story heights and precast concrete beam or inverted precast concrete channel roof systems.

Figure 2-2 Typology D-1 and D-2 school buildings with steel roof framing at a school site located in Yerevan.

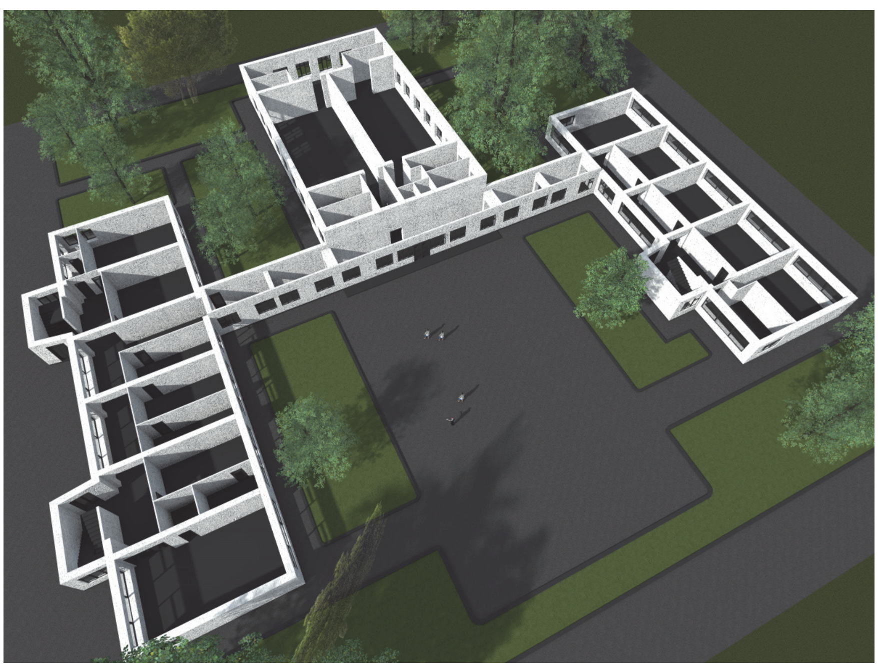


Figure 2-3 Illustration of typical school complex with multiple independent buildings, connected by corridor structures, and separated by anti-seismic joints (from EEC et al., 2015).

In general, the recommendations in these *Guidelines* can be applied to all structural typologies, but the focus of these *Guidelines* has been limited to the three most common historic building types that are also considered the most reasonable candidates for retrofit. Typology A, Typology D-1, and Typology D-2 represent nearly 90% of all school buildings in Armenia. Typology B is the least common building type (approximately 1% of buildings) and Typology C is considered a poor candidate for retrofit (Republic of Armenia, 2015).

As a result, conceptual retrofit schemes are provided for typical classroom and gymnasium buildings for Typology A, Typology D-1, and Typology D-2 construction. Retrofit schemes have not been developed for Typology B and Typology C construction. Similarly, retrofit schemes have not been developed for corridors, stairs, or other miscellaneous structures that might exist at a school site. The configuration and details for miscellaneous structures are highly variable and differ significantly from one location to the next. Engineered solutions for connecting structures and miscellaneous buildings must be individually developed for the specific conditions that are present at each site.

Modern (post-1990) construction consisting of cast-in-place concrete frames with masonry infill walls represents about 10% of school buildings in Armenia. This construction type is not explicitly covered by these *Guidelines*.

2.5 Seismic Deficiencies in Existing School Typologies

Regardless of vintage, existing Armenian school building typologies share many common deficiencies in design, construction, and maintenance resulting in an inventory of school buildings that are highly vulnerable to damage in earthquakes. Common seismic deficiencies include:

- Precast concrete segmented planks for the horizontal framing of floor and roof systems were installed without a cast-in-place concrete topping slab. In the absence of a topping slab, precast planks do not provide the necessary rigidity to develop a diaphragm and distribute earthquake loads to resisting elements.
- Unreinforced masonry is utilized in the structural system to support gravity loads and resist earthquake forces. Unreinforced masonry structures are easily damaged in earthquakes and highly vulnerable to collapse.
- There is a lack of connectivity between the various precast and masonry construction elements. Inadequate connectivity can lead to separation of structural elements and collapse.
- Unreinforced masonry is utilized for interior partitions, including exit corridors. Unreinforced masonry partitions are highly vulnerable to damage, leading to falling hazards and blocking of egress routes.
- Unanchored masonry veneers are used on exterior wall surfaces. Masonry veneers without positive attachment to the structure represent a falling hazard to people outside or exiting a building.
- Anti-seismic joints (gaps between individual buildings) are filled with debris and other materials that will prevent the intended relative movement between buildings, causing unintended pounding or unanticipated torsional response between adjacent structures.

- There is no apparent maintenance program for watertight exterior enclosures, including roofs, walls, and glazing. This has resulted in significant water intrusion along with deterioration and reduction in load-carrying ability of structural components.

All of these issues are compounded by poor quality of construction and lack of inspection of materials and practices during construction.

2.6 Other Armenian Codes and Guidelines

The following documents describe local construction practices and evaluation techniques used in Armenia, including requirements for design and retrofit of stone masonry structures, and technical evaluation of residential, community, and industrial buildings.

- RABC IV-13.01-96, *Stone and Reinforced Masonry Structures* (Margaryan and Davidyan, 1996).
- RABC IV-13.101-2, *Design of Stone and Reinforced Stone Structures* (Margaryan and Davidyan, 2002).
- *Technical Solutions for Buildings with Bearing Stone Masonry Walls for Regions in the Republic of Armenia with 8-9 Seismicity Level* (Margaryan et al., 1991).
- *Recommendations on Reconstruction and Reinforcement of Bearing Structures of Residential Houses of Type IA-450 and Type IA-451 Buildings* (Margaryan et al., 1991).
- *Instructions for Examination of Technical State of Residential, Community and Industrial Buildings and Structures* (Ministry of Urban Development, 2009).

Additional information regarding the development of building codes in Armenia are described in the following:

- "On the draft of antiseismic construction standards in the Republic of Armenia" (Khachiyan, 1992).

2.7 International Standards and Best Practices

"International standards and best practices" refers to proven standards for earthquake-resistant design and construction techniques in other seismic regions of the world, including the United States (California), Japan, and Chile. The documents listed below cover engineering aspects referenced in these *Guidelines*. Where necessary, these documents can be consulted for design solutions in Armenia, provided they do not conflict with the recommendations in these *Guidelines*.

International standards and guides referenced in the development of these *Guidelines* include:

- ACI 318-11, *Building Code Requirements for Structural Concrete* (ACI, 2011). This code provides minimum requirements for materials, design, and detailing of structural reinforced concrete buildings in the United States.
- ACI 506.2-13, *Specification for Shotcrete* (ACI, 2014). This specification contains construction requirements for the application of shotcrete in the United States, including minimum standard for materials, properties, testing, and application.

- ACI 506R-16, *Guide to Shotcrete* (ACI, 2016). This guide is a companion to ACI 506.2-13, providing additional information on shotcrete materials, application procedures, equipment requirements, and qualification and materials testing.
- ASCE/SEI 41-13, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2014). This standard provides performance-based design and acceptance criteria for the seismic evaluation and retrofit of buildings in the United States.
- ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010). This standard specifies minimum load, load combinations, occupancy and risk categories, and design requirements for new buildings and other structures that are subject to U.S. building code requirements.
- *California Building Code* (CBSC, 2016). This State of California code is based on the 2015 *International Building Code* (ICC, 2015), and is modified by the California Division of State Architect for school construction.
- FEMA E-74, *Reducing the Risks of Nonstructural Earthquake Damage—A Practical Guide* (FEMA, 2012). This FEMA product describes sources of nonstructural earthquake damage in simple terms and provides methods for reducing potential risks. The Fourth Edition was released in an electronic format 2012, and provides details and best practices for anchoring nonstructural systems and components in buildings.
- FEMA 547, *Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA, 2006). This document provides a compilation of seismic rehabilitation techniques that are practical and effective. It includes guidance on mitigating specific seismic deficiencies in various model building types, along with detailing and constructability tips.

Other relevant international standards for possible reference and use include:

- NCh433.Of96, *Earthquake Resistant Design of Buildings* (INN, 1996). This document is the principal seismic design standard in Chile, and is a proven benchmark that outlines principles of safe design and construction in a region of very high seismicity.
- *The Standard Law of Japan* (BCJ, 2016). Japanese requirements for earthquake safety in schools have been proven to be rigorous and effective in earthquakes that are larger (in magnitude and duration) than Armenian earthquakes. Although many of the details are not relevant for Armenia, the Japanese code is a useful comparison and outlines solid principles for safe design and construction.
- The following were prepared by the Japan Building Disaster Prevention Association (JBDPA) in Tokyo, Japan, and are multi-volume documents describing aspects of seismic evaluation and damage assessment of concrete structures:
    - *Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings* (JBDPA, 2001a).
    - *The Standard for Criterion of Damage Level and Technical Guideline for Rehabilitation* (JBDPA, 2001b).

- *Guidebook for Earthquake Protection for Nonstructural Elements of School Facilities* (Ministry of Education, 2015). This document provides guidance for inspection and bracing and anchorage of nonstructural elements particular to schools.

2.8 Basis for these *Guidelines*

Armenian building code and construction norms include many important concepts for seismic design that are present in international codes and standards. These include explicit recognition of the potential for building damage in the event of an earthquake, expression of a desired level of performance, and adjustment of design provisions to account for conditions that affect performance, including variation in seismic hazard, site and soil conditions, building response characteristics (resonance), and importance of occupancy and use. They also include specific provisions for schools.

To facilitate technical implementation of these *Guidelines*, Armenian codes and construction norms have been taken as an effective starting point for retrofit and new school design recommendations in these *Guidelines*. Because Armenian codes and construction norms provide minimum standards for design and construction, these *Guidelines* provide supplemental requirements deemed necessary to meet the specified performance objectives for schools, and to raise minimum requirements to levels consistent with international standards and best practices for earthquake-resistant design in regions of high seismicity around the world.

Chapter 3

Earthquake Hazard and Performance Levels

This chapter summarizes Armenian earthquake hazard levels and building performance levels in the form of permissible levels of damage. It also specifies the recommended earthquake hazard level for use in design of school buildings.

3.1 Armenian Earthquake Hazard Levels

Armenia is in the seismically active South Caucuses region, which has a 2,000-year history of strong earthquakes, some of which were recorded by instrumentation, and most of which were not. The historical record indicates that the entire country is at risk of strong earthquakes, and studies have shown that earthquakes larger than M7.0 have repeatedly occurred in the region. The most notable modern earthquake in Armenia is the 1988 M6.9 Spitak earthquake, which was shallow in depth (approximately 11 kilometers), and caused extensive destruction, including 25,000 deaths. Over 900 school buildings were destroyed, including 190 that completely collapsed, resulting in 6,000 school children deaths (Balassanian et al., 1995).

Various deterministic and probabilistic earthquake studies and hazard maps exist, notably from the National Academy of Sciences of the Republic of Armenia (NAS RA), Yerevan State University (YSU), Armenian Scientific Research Institute (Haiseismshin) whose hazard map was adopted by the building codes of the Republic of Armenia in 1994. The potential for peak ground acceleration up to 0.5g around primary fault zones is known to exist. Microzonation studies by the Armenian National Survey for Seismic Protection (NSSP) of the Armenian Ministry of Emergency Situations (MoTAES) exist for several urban areas. Ongoing earthquake monitoring by NSSP and others may produce updated and refined hazard maps in the near future.

Currently, the Republic of Armenia Building Code, RABC II-6.02-2006 (Ministry of Urban Development, 2006), uses the seismic zonation map for the Republic of Armenia that was published in 1994, and divides the country into three zones with estimated peak ground accelerations of 0.2g, 0.3g, and 0.4g (see Figure 3-1). The code requires peak ground accelerations to be multiplied by 1.2 when a site is located within 10 km of active faults, and by 1.2 when the terrain is sloped over 15 degrees (Section 5.2.2 and Section 5.4.2 in RABC II-6.02-2006). Additional amplification is required based on soil category (Table 4 in RABC II-6.02-2006).

3.2 Earthquake Hazard Level for School Design

Given the relatively small geographical size of Armenia, and the considerable uncertainty involved in quantifying earthquake hazard, it is recommended that all retrofitted school buildings and all new school buildings be designed for Seismic Zone 3, the highest seismic zone defined by the code. Additionally, Soil Category III should be assumed for the purpose of calculating seismic design forces. Using site-specific investigations to reduce the seismic demand for any retrofit or new school building design is strongly discouraged.

Sites with poor soil conditions, or other conditions considered unfavorable for construction, such as the potential for landslides, may require higher criteria for design (Section 5.4 in RABC II-6.02-2006).

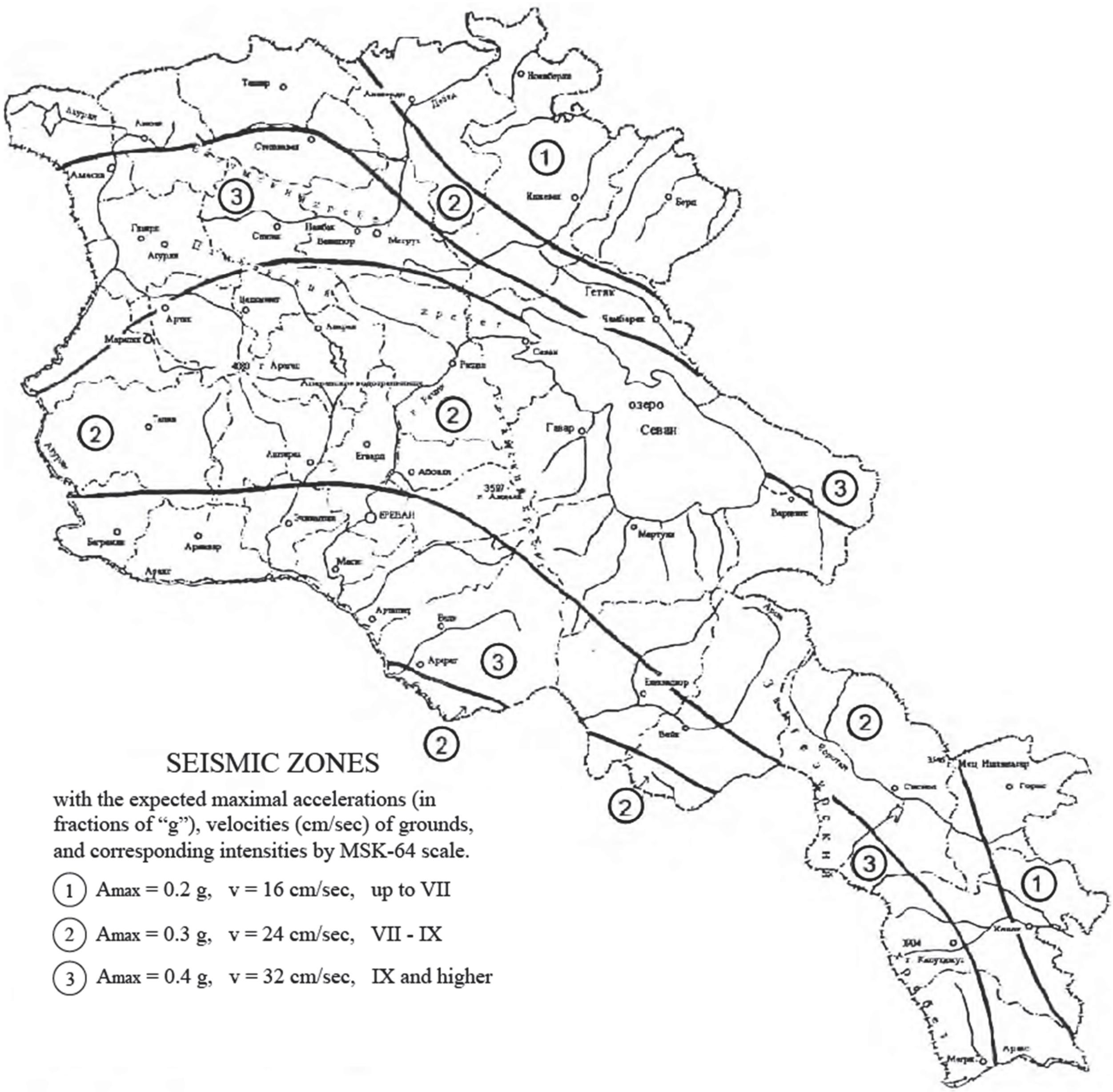


Figure 3-1 Seismic hazard map from the Armenian Building Code (Ministry of Urban Development, 2006).

This conservative approach is appropriate, given the high performance expectations placed on school buildings. International and Armenian experience includes many lessons against underestimating future earthquake risk, and the overall hazard to schools has been demonstrated. Much of the damage in the 1988 Spitak earthquake, for example, was attributable to the low seismic hazard adopted in the seismic code of the former Soviet Union, which was the basis for construction in Armenia at the time (Balassanian et al., 1998; Khachiyan and Margaryan, 1998).

A conservative approach is also practical, given that most schools are concentrated in urban areas, and the three largest cities by population are all located in the highest seismic zone on the Armenian seismic hazard map in RABC II-6.02-2006. Experience with school retrofitting programs in other countries shows that economies of scale will develop from repeated application of the same standards across the inventory of school buildings. In the case of new building construction, it has been shown that overall total construction costs do not change significantly (generally 3% or less) when the seismic hazard is increased (NIST, 2013).

3.3 Performance Levels for School Design

Table 24 in RABC II-6.02-2006 defines five levels of building damage due to earthquakes, ranging from light damage to collapse. The expected variation of damage level with earthquake intensity is illustrated in Figure 3-2. Section 4.1 in RABC II-6.02-2006 identifies light (Damage Extent 1) and moderate (Damage Extent 2) as permissible levels of damage for buildings conforming to RABC II-6.02-2006.

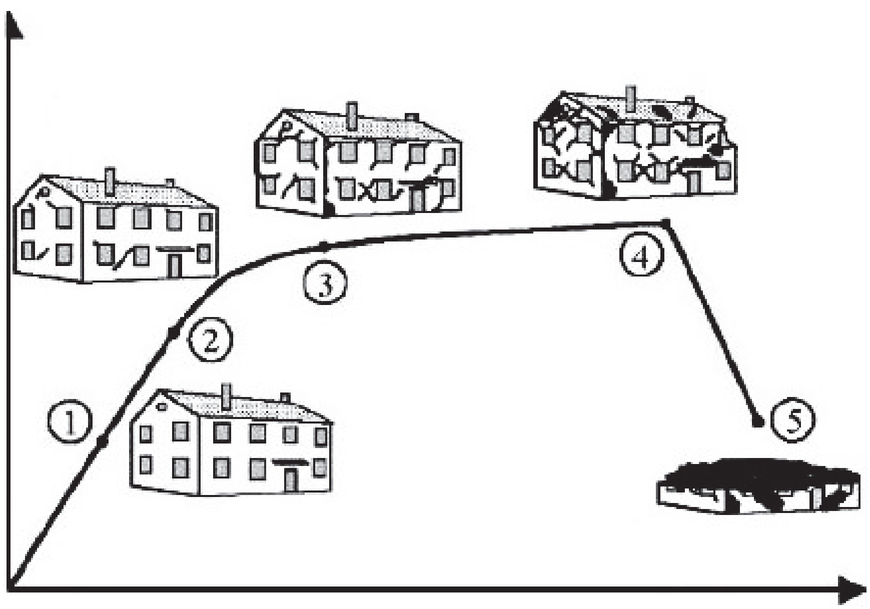


Figure 3-2 Variation of damage level with earthquake intensity (EEC et al., 2006).

The Construction Norms of the Republic of Armenia, CNRA 20-06-2014 (Ministry of Urban Development, 2014) specifies that reinforcement (retrofit) of existing school buildings must meet the requirements of the code for new buildings (RABC II-6.02-2006). Damage levels, and the expected variation of damage with earthquake intensity, generally conform to similar criteria contained in international standards. However, depending on occupancy or importance, international practice often reduces the performance criteria for retrofit of existing buildings relative to criteria for new buildings (ASCE, 2014).

In these *Guidelines*, the recommended performance level for retrofitted and new school buildings directly corresponds to permissible damage levels prescribed in RABC II-6.02-2006 and CNRA 20-06-2014. Permissible damage levels, quantitative indicators of damage, and post-earthquake restoration measures from RABC II-6.02-2006 are summarized in Table 3-1.

Table 3-1 Permissible Damage Levels for School Buildings (from Table 24 of RABC II-6.02-2006)

Damage Extent	*Damage Level*	*Quantitative Indicators of Damage*	*Post-Earthquake Restoration and Strengthening Measures*
1	Light damage to non-bearing elements	(1) small cracks (up to 0.5mm) in plasterwork; (2) spalling pieces of plasterwork; and (3) thin cracks along the edges of partitions and panels.	Renovation of building finishes.
2	Moderate damage to structures	(1) small cracks (0.5-1.0 mm) in stone lintels, piers, walls; (2) spalling large pieces of facing and plasterwork; (3) up to 0.5mm cracks in bearing reinforced concrete elements and concrete slivering (spalling) near the column bases; and (4) damaged chimneys, cornices, concrete pipes, parapets.	Renovation of building finishes and restoration of damaged elements.

Retrofit or new design for typical school building occupancies must conform to Damage Extent 2, moderate damage to structures. Damage Extent 2 describes minor structural damage that is quickly and inexpensively repairable, with potentially more serious damage to cosmetic elements and building systems. Schools damaged to Damage Extent 2 may require repair before re-occupancy.

Retrofit or new design for school buildings intended to serve as emergency shelters must conform to Damage Extent 1, light damage to non-bearing elements. Damage Extent 1 describes schools that are essentially undamaged except for small cosmetic details, and are available for safe occupancy immediately after an earthquake. In addition, to serve as emergency shelters, important building systems must be braced and anchored to protect them from damage. Architectural finishes along with mechanical, electrical, and plumbing systems must allow for continued operation. Otherwise, provisions for emergency power, on-site water storage, and sanitation must be provided.

With the presence of existing non-conforming materials and components, it is not likely that a retrofitted school building will conform to Damage Extent 1, so new school buildings will be better candidates for emergency shelters.

Chapter 4
Retrofit of Existing School Buildings

This chapter outlines data collection, evaluation, and retrofit procedures that are generally applicable to the inventory of existing school buildings in Armenia. Because Armenian school buildings have well-defined, repeatable physical characteristics (typologies), specific guidance on seismic retrofit of typical buildings for selected typologies is also provided. Conceptual seismic retrofit schemes have been developed for typologies that are representative of the most common existing school buildings in Armenia that are also considered the most reasonable candidates for retrofit.

4.1 Procedure for Evaluation of Existing School Buildings

The retrofit design for an existing building will be influenced by the seismic deficiencies present, the condition of the structure, the conditions at the site, and other functional and operational considerations. Evaluation of the building is necessary to inform the retrofit design.

Figure 4-1 presents a recommended format for data collection and evaluation of school buildings that are being considered for retrofit. The purpose of the data collection and evaluation form is to: (1) ensure that a site visit to observe existing conditions is conducted; (2) collect relevant data in an organized and consistent manner; (3) gather information to help determine if the school building is a good candidate for retrofit; (4) describe and assess the condition of the site and buildings; and (5) identify seismic deficiencies that must be corrected as part of the retrofit. A reproducible version of the data collection and evaluation form is provided in Appendix A. This form is intended to be completed by a structural engineer.

Standard plans for each school typology are readily available and should be used to facilitate the data collection and evaluation process. Existing geotechnical information, if available, should be collected and reviewed to understand the underlying soil conditions, and whether or not there is potential for liquefaction, landslide, or surface faulting at the site.

The data collection and evaluation form includes sections to record: (1) basic school building and site information; (2) seismic deficiencies; (3) building condition assessment information; and (4) general comments. One form should be completed for each building, and should be accompanied by photographs documenting all important observations including exterior elevations, seismic deficiencies, structural deterioration, site conditions, and other functional or operational concerns.

SCHOOL DATA COLLECTION AND EVALUATION FORM

SCHOOL BUILDING AND SITE DESCRIPTION

Name of Reviewer(s): ______________________________

School ID: ________________________ **Date:** _________

Location: ____

No. Buildings on Site: _______ **Plans Available:** ☐ Yes ☐ No

Student Capacity: _________ **Current Enrollment:** __________

Building ID: ___________________ **No. Stories:** __________

Dimensions: ___________________ **Story Height:** _________

Year Built: _______ **Year rehabilitated/remodeled:** __________

Description of rehabilitation/remodeling: ________________

____

____

____

Description of Building and Site:
(Attach sketch with the number and configuration of buildings. Label buildings to coordinate with forms.)

____

____

____

____

Structural Typology:

☐ **A:** exterior and interior masonry bearing walls

☐ **B:** exterior masonry bearing walls; interior precast or monolithic concrete frames

☐ **C:** exterior precast concrete frame; interior precast bearing walls

☐ **D-1:** distributed precast concrete frame (up to 2 stories)

☐ **D-2:** distributed precast concrete frame (3-4 stories)

☐ Not defined

☐ Other: ____________________________________

Floor and Roof Construction: ☐ Precast concrete ☐ Wood ☐ Steel

Basement: ☐ Yes ☐ No ☐ Not accessible

Site and Topography: ☐ Flat ☐ Minor sloping site ☐ Major sloping site

Site Hazards: ☐ Landslide zone ☐ Flood zone ☐ Liquefaction zone ☐ Within 10 km of a mapped fault

Past Earthquake Studies Performed:
(List by organization and date.)

____

____

SEISMIC DEFICIENCIES

(Check all that apply and include photos to document.)

Roof:
- ☐ Precast concrete planks without topping slab
- ☐ Wood or steel construction with inadequate diaphragm

Floors:
- ☐ Precast concrete planks without topping slab
- ☐ Wood construction with inadequate diaphragm

Exterior Walls:
- ☐ Bearing walls of unreinforced masonry or stone construction
- ☐ Non-bearing walls of unreinforced masonry or stone construction
- ☐ Inadequately anchored masonry veneer
- ☐ Inadequately anchored precast wall panels

Interior Walls:
- ☐ Bearing walls of unreinforced masonry or stone construction
- ☐ Unreinforced masonry partitions

Structural Frame and Connectivity:
- ☐ Precast concrete beam-column frame construction
- ☐ Weak/non-ductile precast concrete frame connections
- ☐ Lack of positive connection between masonry walls and floor or roof diaphragms
- ☐ Lack of positive connection between precast floor/roof planks and supporting frames or walls
- ☐ Anti-seismic joints are filled with debris

Foundation:
- ☐ Rubble strip foundations under bearing walls
- ☐ Isolated pad foundations without grade beams

Seismic Anchorage of Nonstructural Components:
- ☐ Unanchored tall furnishings (bookshelves, file cabinets)
- ☐ Unbraced suspended ceilings or lights
- ☐ Unanchored mechanical equipment
- ☐ Unbraced parapets or chimneys

Other Observed Deficiencies: ____

____

Figure 4-1 School data collection and evaluation form (page 1).

BUILDING CONDITION ASSESSMENT

(Check all that apply and include photos to document.)

Structural Condition:

Evidence of corrosion of reinforcing steel or spalling of concrete at:

- ☐ Roof
- ☐ Floors
- ☐ Connections
- ☐ Other: ____________________

Evidence of vertical distress including significant deflection or loss of vertical-load-carrying capacity at:

- ☐ Roof
- ☐ Floors
- ☐ Connections
- ☐ Other: ____________________

Evidence of prior damage or distress:

- ☐ Cracking on underside of floor or roof framing
- ☐ Diagonal cracking in walls
- ☐ Cracking in beams, columns, or in vicinity of joints
- ☐ Cracking in foundations
- ☐ Other: ____________________

Structural Condition (continued):

Evidence of differential settlement or foundation movement:

- ☐ Yes
- ☐ No

Building Envelope and Site Condition:

- ☐ Improper or inadequate slope for drainage at site
- ☐ Evidence of significant water intrusion
- ☐ Evidence of failure in roofing
- ☐ Evidence of failure in seals around windows and doors
- ☐ Notes on general condition of envelope or site:

____

____

Overall Building Condition:

- ☐ Good: Minor repairs necessary in addition to seismic retrofit
- ☐ Fair: Significant repairs necessary in addition to seismic retrofit
- ☐ Poor: Major repairs necessary in addition to seismic retrofit
- ☐ Notes on general condition of building:

____

____

Other Functional or Operational Considerations:

- ☐ Roof and site rain water is properly controlled and directed away from the building (and off site)
- ☐ The roofing envelope has been maintained in good condition to prevent water intrusion
- ☐ Exterior windows and glazing have been updated for energy efficiency and maintained to prevent water intrusion
- ☐ Mechanical and electrical systems have been updated for energy efficiency and maintained in good condition
- ☐ Interior finishes have been updated or modernized
- ☐ Past evidence of structural damage has been repaired and maintained in good condition
- ☐ Anti-Seismic joints are clear and gaps are functioning as intended

GENERAL COMMENTS

(Consider building age, condition, deficiencies, possible historic significance, demographics, and other functional or operational considerations to provide an overall opinion on the feasibility for retrofit and recommended prioritization.)

____

____

____

____

Instructions for use:

- A separate form should be completed for each building at the site (defined by location of anti-seismic joints).
- Important observations, including exterior elevations, seismic deficiencies, structural deterioration, site conditions, and other functional or operational concerns should be documented with photographs.
- Standard plans for each school typology are readily available and should be used to facilitate data collection and evaluation.
- Existing geotechnical information, if available, should be collected and reviewed to understand the underlying soil conditions.
- Investigation of existing foundations (when plans are not available) is difficult and costly. When necessary, foundations can be investigated through observation pits excavated at specific locations. When foundation conditions are not known, assumptions made during design must be confirmed, and modified as necessary, based on field observations during construction.

Figure 4-2 School data collection and evaluation form (page 2).

4.1.1 School Building and Site Description

This section is used to collect data on the building and site, including the physical configuration and dimensions of the building, year built, year rehabilitated or remodeled, the structural typology, site topography, and potential site hazards. It also includes other information, such as student capacity and student population, that might factor into functional and operational considerations.

Basic building and site information is used to determine the structural typology of the building, which is used to determine the initial suitability for retrofit and the likely retrofit approach. Information on site topography and site hazards is necessary for evaluating code provisions related to site factors and values of peak ground acceleration for design. It is also necessary to determine the possible need for more substantial site investigation and special foundation design solutions to address potential liquefaction, landslide, or surface faulting at the site.

4.1.2 Seismic Deficiencies

This section is used to itemize seismic deficiencies that are present in the building under consideration. It is presented in a checklist format for simplified identification of deficient conditions. The checklist consists of a list of building characteristics that are known to result in significant damage, collapse, or loss of life in earthquakes, and includes conditions that are commonly found in existing Armenian school building typologies.

The existence of a condition in the checklist is considered a seismic deficiency. Existing school typologies were designed with little or no consideration of seismic effects, and building components are likely to be of low quality or deteriorated due to lack of maintenance. As such, existing structures will have very little capacity to resist seismic forces. Engineering calculations to evaluate seismic capacity versus seismic demand are not expected to demonstrate compliance with Armenian code requirements or international standards for performance of school buildings, and are strongly discouraged.

An itemized list of seismic deficiencies is used to determine the scope and extent of the work required. The eventual retrofit design must remove all seismic deficiencies identified in the building.

4.1.3 Building Condition Assessment

This section is used to collect visual data on the overall condition of the building, possible deterioration in structural components, performance of the foundation, and integrity of the building envelope. Significant deterioration and loss of load-carrying ability in structural components is possible due to water intrusion and lack of long-term maintenance. The condition of the existing structure will affect the design and construction of retrofit measures, and must be considered in the retrofit design.

If visual evidence of deterioration is present, quantitative investigation of the residual capacity of existing materials and components is needed before they can be included in a retrofit design. The expense of repairing a severely deteriorated building, including repair or replacement of structural components and restoration of the building envelope, will affect the total cost of work and the overall suitability of the building for retrofit.

If evidence of differential settlement or foundation movement resulting in visible structural damage is present at the site, a geotechnical investigation should be performed to determine the condition of the underlying soils and appropriate values for foundation design.

4.1.4 General Comments

This section is used to record general comments by the reviewer on the overall feasibility and potential effectiveness of a seismic retrofit solution for the building under consideration. This information should be combined with demographic information, the age of the building, condition of the building, possible historic significance, and potential costs for modernization, to help decision-makers determine the best course of action, such as retrofitting the school building or replacing it with new construction. From a structural perspective, building age and condition are key contributing factors for deciding between retrofit or replacement.

4.2 General Seismic Retrofit Requirements

Existing Armenian school buildings utilize archaic materials and structural systems that have been known to perform poorly in past earthquakes. Because of their occupancy and importance, however, school buildings have an elevated expectation of performance, both in Armenia, and internationally. The general seismic retrofit approach must achieve this elevated expectation of performance to extend the useful life of school buildings.

Armenian code requirements for typical school buildings limit the permissible level of damage in an earthquake to Damage Extent 2, described as moderate damage consisting of: small cracks (0.5-1.0 mm) in stone lintels, piers, walls; some spalling of facing and plasterwork; cracking (up to 0.5mm) in bearing reinforced concrete elements; some spalling of concrete near the bases of columns; and some damage to chimneys, cornices, concrete pipes, and parapets.

To limit damage as a performance objective, the seismic retrofit approach is to provide additional strength to resist earthquake forces, and additional stiffness to limit building movement (drift) in an earthquake. To minimize potential for cracking, spalling, or fracture of connections, archaic materials and systems used to resist earthquake forces are supplemented with shear wall systems constructed using modern reinforced concrete materials for improved seismic performance. Similarly, to protect against the potential for collapse, archaic materials and systems used for gravity support are supplemented with new reinforced concrete to reliably maintain vertical load-carrying ability.

To provide a higher level of confidence in achieving the required performance objective, a conservative design approach along with certain simplifying assumptions are made to minimize some of the variability and uncertainty that can be associated with seismic design. The following sections provide requirements deemed necessary for seismic retrofit designs to meet the specified Armenian performance objectives for schools, consistent with international standards and best practices for earthquake-resistant design in regions of high seismicity around the world.

4.2.1 Building Code and Construction Norms

Seismic retrofit of school buildings should conform to the requirements of the Republic of Armenia Building Code, RABC II-6.02-2006 (Ministry of Urban Development, 2006), and Construction Norms of the Republic of Armenia, CNRA 20-06-2014 (Ministry of Urban Development, 2014), as modified by these *Guidelines*.

The term "retrofit" in these *Guidelines* is most closely aligned with the term "reinforcement" defined in CNRA 20-06-2014 as construction necessary to increase a building's seismic resistance to comply with current Armenian building codes and construction norms.

4.2.2 Material Design Standards

Reinforced concrete design and construction used in retrofit of school buildings should conform to SNiP 2.03.01-84*, *Concrete and Reinforced Concrete Structures* (SNIP, 1984), with the following additional specific requirements based on requirements in ACI 318-11 (ACI, 2011):

- Minimum concrete strength (unless otherwise noted): 20 MPa (cylindrical strength); this corresponds to B30 concrete.
- Minimum reinforcement steel strength: 500 MPa. It is recommended to use grade A500C for all steel reinforcement. All reinforcing bars should be deformed. Smooth or twisted bars are not permitted.
- Lap splices in reinforcement should not be less than 40 bar diameters for concrete in compression, and 60 bar diameters for concrete in tension, but not less than 60 cm as a minimum.
- Mesh is not recommended as mesh typically does not have the same level of quality and ductility as deformed bar reinforcement, and is prone to fracture at welds.

4.2.3 Use of Existing Materials and Components

In general, existing materials and components participating in the seismic force-resisting system are not expected to conform to Damage Extent 2, and are not recommended for reliably resisting earthquake forces. Use of existing components in the retrofit design requires knowledge of as-built materials. Because existing components will not be relied upon to resist earthquake forces, material testing of existing concrete, reinforcing steel, or masonry (in-situ or in the laboratory) will not generally be necessary. Conservative values for in-situ materials should be assumed when needed. In the case of deteriorated structural components, and possible concern over continued support of gravity loads, quantitative investigation of the strength of materials and components should be performed, or they should be repaired or replaced.

4.2.4 Seismic Zone and Site Classification

For seismic retrofit of schools, it is recommended that all locations be considered Seismic Zone 3, which is the highest seismic hazard in Armenia. Soil Category III should be assumed for the purposes of calculating seismic loads. If settlement (differential or uniform) has caused visible structural damage to the building, a soil investigation should be conducted.

School construction is prohibited on Soil Category IV per Section 7.14 in RABC II-6.02-2006. If an existing school is located on Soil Category IV or on a site that is considered unfavorable for construction per Section 5.4.1 in RABC II-6.02-2006, the school should not be considered for retrofit, and should be relocated.

4.2.5 Seismic Analysis Procedure

Seismic retrofit designs may be based on equivalent lateral force procedures and linear analysis techniques. Section 6.4.1 in RABC II-6.02-2006 provides the equation for calculating horizontal seismic loads for design. For seismic retrofit of school buildings, the following values should be used:

- The soil factor, k_o, should be taken as 1.1 (per Table 4 in RABC II-6.02-2006, assuming Seismic Zone 3 and Soil Category III).
- The permissible damage coefficient, k_1, should be taken from Table 7 in RABC II-6.02-2006 assuming Seismic Zone 3. When analyzing the retrofitted structure, the value for the new system (for example, concrete walls) must be used.
- The importance coefficient, k_2, should be taken as 1.3 for schools, per Table 8 in RABC II-6.02-2006.
- The soil-structure interaction coefficient, k_3, should have a value of 0.7 or greater per Section 6.8.2 in RABC II-6.02-2006.
- The dimensionless coefficient of seismicity, A, should be 0.4, consistent with the assumption of Seismic Zone 3.
- The dimensionless dynamic coefficient, β, should be taken as 2.5.
- For sites within 10 km of known mapped faults, horizontal ground acceleration values should be multiplied by 1.2 per Section 5.2.2 in RABC II-6.02-2006.

4.2.6 Retrofit Design Requirements

New elements of the seismic force-resisting system should be designed to resist 100% of the calculated horizontal seismic loads. The retrofit design should not rely on existing archaic materials or structural systems to resist horizontal seismic loads. The new seismic force-resisting system should be symmetric to the extent possible. Because existing buildings will have geometric limitations, retrofit designs should explicitly account for any differences between the center of mass and center of rigidity.

Connections between elements of the seismic force-resisting system should be detailed to provide ductility, allow for the expected movement (drift), and be designed develop the capacity of the connected members, where possible.

Period limitations in Section 7.1.8 of RABC II-6.02-2006 may be neglected for retrofit of school buildings. These provisions are important for avoiding resonance in tall buildings on soft soil sites, and become less important for low-rise buildings on typical soil sites.

4.2.7 Limitations on the Number of Stories

School buildings are limited to three stories in height per Section 7.3.7 in RABC II-6.02-2006. School buildings exceeding three stories in height should not be considered for retrofit unless the upper stories are removed. Simply vacating floors above the third story will not meet this requirement. Basements that are more than 50% above grade are considered a story.

4.2.8 Drift Limits

Drift limits should conform to values provided in Table 7 of RABC II-6.02-2006. Because retrofitted school buildings will still contain elements and connections from the original materials and systems, drift limits should correspond to the original type of construction.

4.2.9 Diaphragms, Collectors, and Connections

A rigid floor and roof structure is necessary as a diaphragm to distribute seismic loads to the elements of the seismic force-resisting system, and to anchor exterior and interior walls for out-of-plane forces.

Existing precast concrete floor and roof systems should be supplemented with a reinforced cast-in-place concrete topping slab. In cases where existing floor and roof systems are not able to support the added weight of a topping slab, such as deteriorated or unusual long-span conditions, provisions for additional gravity support are required. These include repair or replacement of deteriorated floor or roof framing, construction of supplemental gravity framing, or design of the new topping slab to perform in a monolithic fashion with the existing framing.

Collectors and chords that are integral with new topping slab should be provided to distribute seismic loads to the new elements of the seismic force-resisting system. No credit should be given to existing belt systems that may be present in the building.

Positive attachment should be provided between the topping slab and new and existing walls in the building. Connections should be designed for out-of-plane forces in accordance with Section 6.12 in RABC II-6.02-2006.

4.2.10 Foundations

If there is no evidence of building settlement, no evidence of structural damage resulting from settlement, and no other visible problems with the existing foundation, additional gravity load up to 10% of the total existing gravity load on the structure may be added to existing concrete foundations without reinforcement (based on similar requirements in the California Building Code (CBSC, 2016)). No additional loads may be added to existing stone or rubble foundations without engineered reinforcement.

Foundations under new shear walls should be checked for overturning stability. For short (or non-continuous) shear walls, new grade beams or friction piles may be necessary for overturning resistance to prevent rocking. Friction piles may only be used to resist uplift, not for vertical bearing, per Section 7.4 in RABC II-6.02-2006.

Additional design requirements for foundations provided in Section 7.4 of RABC II-6.02-2006 should also be followed.

4.2.11 Nonstructural Considerations

All interior non-bearing, unreinforced masonry partitions that are not being strengthened to act as new shear walls, including walls separating classrooms and corridors, should be demolished and replaced with modern lightweight interior partitions consisting of steel studs and gypsum wallboard. Use of modern lightweight partitions will reduce seismic demand and eliminate falling hazards associated with unreinforced masonry partitions.

Masonry veneers weighing less than 50 kg/m^2 may be bonded to the substructure with grout developing a working bond stress of 345 kPa. Unless the existing anchorage is proven to be adequate, veneers should be mechanically anchored or removed and reinstalled with proper adhesive anchorage. Veneers heavier than 50 kg/m^2 should be removed from the structure. In general, removal of existing veneers is recommended because proper anchorage of veneers is difficult, even when properly designed. If adhered veneers are used, a special inspection program is required to ensure proper construction.

Exterior precast panels, equipment, parapets, suspended piping, and service lines that pose falling hazards should be braced and positively anchored to the structure per Section 6.12 and Section 7.1.9 of RABC II-6.02-2006. Chapter 6 in these *Guidelines* provides specific recommendations for anchoring and bracing nonstructural components that are commonly found in school buildings in Armenia.

4.2.12 Miscellaneous Structures

Interconnecting corridors, stairs, and other miscellaneous structures that exist at a school site should be individually retrofitted using similar technologies, and should be separated from adjacent buildings with anti-seismic joints to allow relative movement during an earthquake. Section 7.3 in RABC II-6.02-2006 provides additional requirements related to anti-seismic joints.

4.3 Alternative Seismic Retrofit Solutions Considered

In developing the general recommended seismic retrofit approach, many different local and international design and construction techniques were considered. Alternatives were evaluated against the following criteria: (1) applicability and ease of use within local Armenian design and construction practices; (2) effectiveness in controlling drift and protection of archaic materials and systems for meeting Armenian performance objectives for schools; and (3) consistency with international best practices.

The following documents describe local construction practices for design and retrofit of stone masonry structures that are available:

- RABC IV-13.01-96, *Stone and Reinforced Masonry Structures* (Margaryan and Davidyan, 1996).
- RABC IV-13.101-2, *Design of Stone and Reinforced Masonry Structures* (Margaryan and Davidyan, 2002).

- *Technical Solutions for Buildings with Bearing Stone Masonry Walls for Regions in the Republic of Armenia with 8-9 Seismicity Level* (Margaryan et al., 1991).
- *Recommendations on Reconstruction and Reinforcement of Bearing Structures of Residential Houses of Type IA-450 and Type IA-451 Buildings* (Margaryan et al., 1991).

Additionally, the report, *Preventing Disaster Losses and Reducing Vulnerability of Children in Armenia* (EEC et al., 2015) describes the potential application of modern, innovative technologies to school buildings in Armenia.

The following seismic retrofit techniques and procedures were explicitly considered in developing the general retrofit approach, although they were ultimately not recommended for use in existing school buildings in Armenia:

- **Partial/corner "jacketing" and seismic "belting."** These technologies consist of banding the buildings together with reinforced concrete seismic "belts" around the perimeter and adding "jackets" of reinforced concrete to strengthen certain load-carrying elements and connections in the building. These techniques have been used in Armenia to reduce the vulnerability of existing buildings, in particular of residential buildings and houses of stone masonry construction, by strengthening the most vulnerable parts of the structure. These techniques are cost-effective, but are only appropriate for certain buildings because they provide a limited level of safety. They continue to rely on archaic masonry materials for seismic resistance, and do not completely address the potential for damage and collapse associated with multi-course stone masonry wall construction. Because of the required performance standards for schools in RABC II-6.02-2006, these techniques were not considered appropriate for school buildings.
- **Seismic isolation.** Seismic isolation separates the building structure from its foundation through the use of slide bearings and the construction of a perimeter moat around the building to allow relative movement. Base isolation is effective in reducing the seismic forces transmitted into the structure. Internationally, this technology is considered expensive, and is used in buildings that contain valuable contents (such as museums), or in structures of cultural or historic value. Base isolation does not remove the need to strengthen and stiffen structures with weak or brittle connections, such as those found in existing Armenian school buildings. Properly implementing this technique was considered overly complex, difficult, and cost-prohibitive for large scale application to the inventory of school buildings in Armenia.
- **Dampers and buckling-restrained bracing systems.** Viscous and friction dampers and buckling-restrained braced frame (BRBF) systems reduce earthquake demands in buildings through an increase in structural damping or change in building period. These systems are used internationally, and are effective in controlling earthquake response in frame systems, but are not considered effective in combination with wall systems. Generally, damping and BRBF technologies were considered more expensive to implement and more difficult to implement properly, because they require advanced engineering for proper application, utilize imported materials and labor, and require significant ongoing maintenance to function properly.

4.4 Seismic Retrofit of Typology A: Masonry Bearing Wall Construction

Typical Typology A buildings are one to four stories tall, with a story height of 3.3 meters for classrooms (Figure 4-3) and 5.6 meters for gymnasiums (Figure 4-4). Typology A buildings include interior and exterior bearing walls of stone masonry (complex) construction, precast concrete or wood frame floor and roof systems, and unreinforced masonry interior partitions. Bearing walls are typically 50 cm thick.

Typology A schools are typically composed of multiple wings (buildings) with rectangular plans, connected by corridors, and separated by anti-seismic joints. Figure 4-5 illustrates a typical Typology A school site consisting of two rectangular wings connected by a single corridor structure. Figure 4-6 shows the typical wall layout for two-story Typology A school buildings.

Figure 4-3 Typical two-story Typology A classroom building.

Figure 4-4 Typical Typology A gymnasium building.

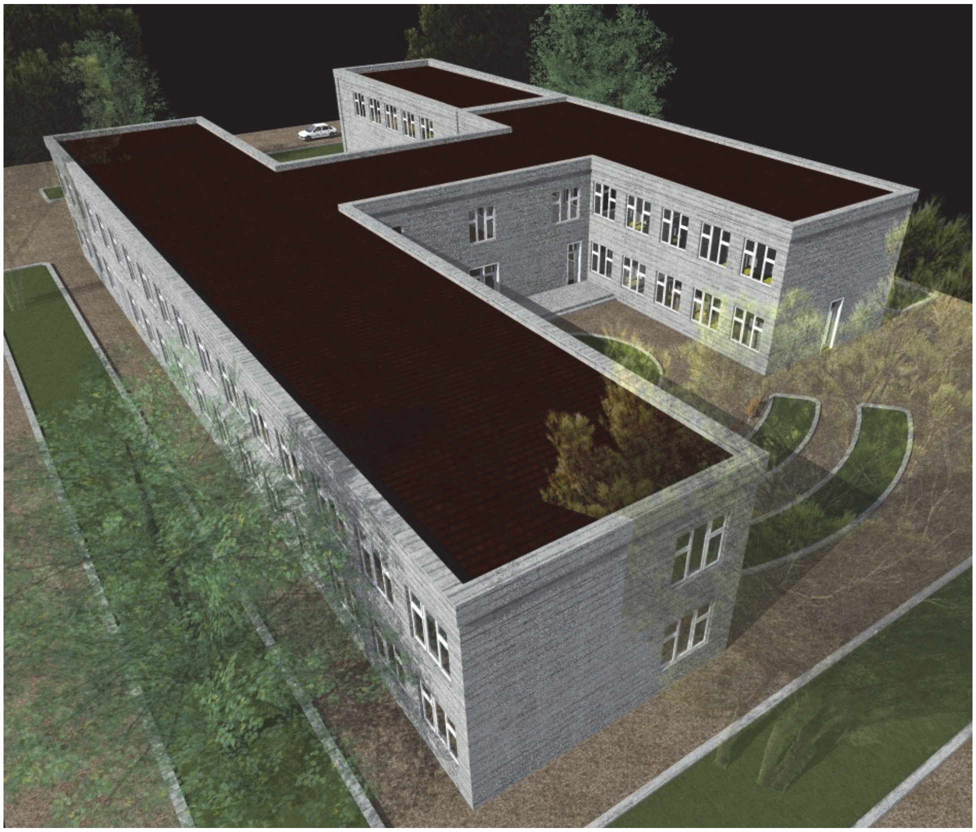


Figure 4-5 Typical Typology A school site with two buildings connected by a corridor structure (EEC et al., 2015).

Figure 4-6 Typical wall layout for two-story Typology A school buildings (EEC et al., 2015).

Gymnasiums and auditoriums are long-span, open structures with tall stories existing as separate buildings or occupying portions of other buildings on a school site. Typology A gymnasium and auditorium structures typically have tall unreinforced masonry bearing walls around the perimeter with large window openings. Roof structures typically consist of: (1) prestressed reinforced concrete beams supporting reinforced precast ribbed slabs; or (2) precast reinforced concrete ribbed slabs spanning about nine meters.

Typology A buildings can be categorized by date as: (1) pre-1960 buildings, which were individually designed with no seismic considerations, are typically of architectural or cultural value, and utilize non-typical or "complex" masonry and other construction materials; and (2) post-1960 buildings, which typically use precast segmented concrete floor and roof structures and multi-wythe tufa bearing walls, and were typically designed for minimal seismic forces (approximately 0.10g).

These *Guidelines* specifically address post-1960 Typology A buildings because: (1) pre-1960 schools are likely to be nearing the end of their useful life, and will soon need to be replaced; and (2) pre-1960s buildings that might be preserved are likely to be of historic value, which will require special considerations for retrofit that are outside the scope of these *Guidelines*.

4.4.1 Seismic Deficiencies of Typology A Buildings

Unreinforced masonry bearing wall buildings, in general, and stone masonry buildings, in particular, have demonstrated poor performance in past earthquakes. Unreinforced masonry bearing walls have little capacity to resist in-plane and out-of-plane forces and deformations associated with earthquakes, resulting in extensive diagonal cracking and subsequent loss of vertical and lateral load-carrying ability. Weak or inadequate diaphragms provide limited ability to develop wall anchorage forces into the building and distribute loads to other elements of the seismic force-resisting system. Poor connections at floor and roof diaphragms provide inadequate anchorage resulting in out-of-plane collapse of walls and supported areas of the floor and roof framing. The following seismic deficiencies identified on the data collection and evaluation form are present in Typology A buildings:

- exterior and interior bearing walls of unreinforced masonry or stone construction;
- roof and floor framing consisting of precast concrete planks without topping slabs;
- lack of positive connection between masonry walls and floor or roof diaphragms;
- lack of positive connection between precast floor/roof planks and supporting frames or walls;
- rubble strip foundations under bearing walls; and
- anti-seismic joints filled with debris.

Many Typology A school buildings also have additional vulnerabilities, such as poor quality materials, poor quality workmanship, and lack of maintenance.

4.4.2 Seismic Retrofit of Typology A Buildings – Typical Classroom Building

This section presents a conceptual seismic retrofit scheme for a typical classroom building of Typology A construction. Because of well-defined, repeatable physical characteristics, this conceptual design is generally applicable to Typology A buildings with the same (or similar) characteristics. However, it is not a prescriptive engineering solution for any one specific building. As a result, implementation of this scheme to a specific building will require the involvement of an engineer to evaluate the applicability of the recommended solution to each individual school building and the conditions that are present at each existing school site.

This conceptual seismic retrofit scheme is applicable to post-1960 Typology A classroom buildings, of one to three stories in height, with precast concrete floor and roof systems. Connecting structures, such as corridors between classroom wings, are not included in this scheme, but should be retrofitted with similar concepts using a similar engineering approach. This scheme was designed using the following assumptions:

- The school is located on a flat site (defined as a slope of 10% or less). Sloped sites are special cases that require additional engineering attention.
- The school is not located within 10 km of a fault. School sites located within 10 km of a fault must be designed for increased horizontal ground accelerations.

To eliminate seismic deficiencies in Typology A typical classroom buildings, the following retrofit measures are recommended. A structural narrative describing the measures in more detail, along with conceptual plans and typical details are provided in Appendix B.

- To provide sufficient strength and stiffness to limit potential damage, all existing masonry bearing walls should be supplemented with new reinforced concrete shear walls. The new reinforced concrete should be designed to take 100% of the specified in-plane seismic loads and should be sized to adequately brace the walls for out-of-plane loading. Reinforced concrete may be omitted by design in isolated areas where obstructions exist along existing walls.
- Two-sided application of new reinforced concrete to existing masonry walls would be expected to provide superior earthquake performance; however, this option was considered cost-prohibitive, not architecturally sensitive, and not absolutely required in all cases.
- To preserve the exterior appearance of buildings, and minimize potential costs, exterior masonry bearing walls have been designed to receive new reinforced concrete on the inside face of the walls. If the design requires the closure of existing windows, the need for minimum lighting and ventilation requirements should be considered.
- To provide reliable gravity load support for floor and roof framing on each side, interior masonry bearing walls have been designed to receive new reinforced concrete on both faces of the walls.
- Guidance on preparing masonry walls to receive new reinforced concrete, including the removal of loose mortar between the blocks to a depth of 2 to 3 cm, is provided in Section 2.4.10 of *Recommendations on Reconstruction and Reinforcement of Bearing Structures of Residential Houses*

of Type IA-450 and Type IA-451 Buildings (Margaryan et al., 1991). In most cases, loose mortar is expected to be removed as part of the process of removing existing plaster finishes.

- Dowels consisting of through-bolts with exterior bearing plates are necessary to tie the multi-wythe complex masonry wall construction to the new reinforced concrete walls for out-of-plane stability and for protection against damage due to in-plane earthquake loads and deformations.
- To provide diaphragms for anchoring walls out-of-plane, and transferring seismic forces to the new elements of the seismic force-resisting system, new reinforced concrete topping slabs should be installed over existing precast planks at the floor and roof levels. Existing floor and roof surfaces must be prepared for the application of topping slabs through removal of floor finishes and roofing materials, and the cleaning and roughening of the exposed concrete surfaces.
- New collectors to distribute seismic loads to the new reinforced concrete shear walls are generally not required in this scheme because: (1) all load-bearing walls have new distributed reinforced concrete shear walls along their entire length; and (2) direct shear transfer of all diaphragm loads to the walls, and the foundation, is possible through dowels provided along the length of the walls.
- The installation of new reinforced concrete shear walls and topping slabs will add significant additional gravity load to the structure. The design should include reinforcement of existing foundations to transfer new loads to existing foundation elements and the supporting soils, and to help maintain the integrity of existing rubble foundations.
- The thickness and strength of concrete, and size and spacing of reinforcement, must be engineered for each school building at each site. The following minimums were assumed in the design of the recommended scheme for typical classroom buildings:
  - Minimum thickness of concrete for shear walls:
    - 10 cm for single-story buildings,
    - 10 cm for 2-3 story buildings if using double-sided concrete walls, and
    - 15 cm for 2-3 story buildings if using single-sided concrete walls.
  - Minimum thickness of concrete for topping slabs: 65 mm. Lightweight concrete may be used for topping slabs to reduce the added weight.
  - Minimum strength of concrete: 20 MPa (cylindrical strength).
  - Maximum spacing of reinforcing bars in shear walls and topping slabs: 20 cm each way.
  - Maximum spacing of anchors between existing masonry walls and new reinforced concrete: 60 cm each way staggered.
  - Maximum allowable design shear capacity for new reinforced concrete shear walls: $0.7\sqrt{f'_c}$ [MPa].
  - Minimum typical trim reinforcement is provided around all openings in shear walls.

- To minimize seismic mass and potential falling hazards, all interior masonry partitions should be removed and replaced with modern lightweight cold-formed steel studs and gypsum wallboard construction.
- To allow individual buildings to move independently, avoid pounding damage, and prevent unintended torsional response, existing anti-seismic joints must be cleared of debris, widened to accommodate the expected seismic drifts, and protected to avoid future accumulation of debris.

4.4.3 Seismic Retrofit of Typology A Buildings – Typical Gymnasium Building

This section presents a conceptual seismic retrofit scheme for a typical long-span, tall-story gymnasium building of Typology A construction. This conceptual design is generally applicable to Typology A gymnasium buildings with the same (or similar) characteristics, but is not a prescriptive engineering solution for any one specific building. Implementation of this scheme to a specific building will require engineering evaluation of the applicability of the recommended solution to each individual building and the conditions that are present at each existing school site.

To eliminate seismic deficiencies in Typology A typical gymnasium buildings, the following retrofit measures are recommended. A structural narrative describing the measures in more detail, along with conceptual plans and typical details are provided in Appendix B.

- To provide sufficient strength and stiffness to limit potential damage, all existing masonry bearing walls should be supplemented with new reinforced concrete shear walls. The new reinforced concrete should be designed to take 100% of the specified in-plane seismic loads and should be sized to adequately brace the walls for out-of-plane loading. Reinforced concrete may be omitted by design in isolated areas where obstructions exist along existing walls.
- Two-sided application of new reinforced concrete to existing masonry walls is necessary to adequately brace the walls out-of-plane because of tall story heights.
- Guidance on preparing masonry walls to receive new reinforced concrete, including the removal of loose mortar between the blocks to a depth of 2 to 3 cm, is provided in Section 2.4.10 of *Recommendations on Reconstruction and Reinforcement of Bearing Structures of Residential Houses of Type IA-450 and Type IA-451 Buildings* (Margaryan et al., 1991). In most cases, loose mortar is expected to be removed as part of the process of removing existing plaster finishes.
- Dowels through the existing masonry walls are necessary to tie the multi-wythe complex masonry wall construction to the new reinforced concrete walls on each side for out-of-plane stability and for protection against damage due to in-plane earthquake loads and deformations.
- To provide a roof diaphragm for anchoring walls out-of-plane, a new reinforced concrete topping slab should be installed over the existing long-span precast concrete roof structure. The ability of the existing roof structure to support the additional gravity loads must be verified, or supplemental gravity support must be provided. The surface should be prepared for the application of a topping slab through removal of roofing materials, and the cleaning and roughening of the exposed concrete surface.

- Adequate connection for in-plane and out-of-plane forces between the walls and the roof diaphragm is necessary through dowels provided along the length of the walls.
- The installation of new reinforced concrete shear walls and topping slab will add significant additional gravity load to the structure. The design includes reinforcement of existing foundations to transfer new loads to existing foundation elements and the supporting soils, and to help maintain the integrity of existing rubble foundations.

4.4.4 Possible Alternative Seismic Retrofit Measures for Typology A Buildings

The conceptual seismic retrofit solutions outlined in Section 4.4.2 and Section 4.4.3 have been recommended considering local Armenian design and construction practices, ease of design and construction, and reliability in achieving the required performance of school buildings in an earthquake. Use of alternative retrofit measures will affect constructability and estimated construction costs to varying degrees. This section presents alternative retrofit measures that could be considered for Typology A buildings. Individual trade-offs for costs and benefits associated with the use of alternative retrofit measures should be considered on a case-by-case basis.

- **Use of shotcrete in lieu of cast-in-place concrete.** Shotcrete is regularly used in U.S. retrofit practice. Because shotcrete does not require the labor, time, and expense associated with the construction of concrete forms, it is a cost-effective alternative for application of reinforced concrete on the surface of existing walls. Existing Armenian technologies for shotcrete application appear to differ from the international state of knowledge and practice. As a result, more expensive cast-in-place concrete has been used in the conceptual design. However, significant potential reductions in cost (on the order of 20%) are possible if international shotcrete technologies, such as those found in ACI 506.2-13, *Specification for Shotcrete* (ACI, 2014) and ACI 506R-16, *Guide to Shotcrete* (ACI, 2016) were imported for use in Armenia. Properly designed and constructed shotcrete can be used in place of cast-in-place concrete with no sacrifice in performance. Proper construction of shotcrete, however, will require additional quality control measures including pre-qualification of experienced nozzle operators and inspection during installation.
- **Use of epoxy anchors in lieu of through-bolts and exterior bearing plates.** Epoxy anchor technologies are available in Armenia and internationally. Epoxy anchors could be considered for one-sided application on exterior walls, however, this option is highly dependent on installation and quality control. Through-bolts and exterior bearing plates have been recommended as the most reliable method of engaging the multi-wythe, complex construction of the existing masonry walls. Alternative epoxy anchors must engage the outer wythe of the stone masonry walls, and will likely require closer spacing than equivalent through-bolts. The proper use of epoxy anchors will also require a special testing program (for both the epoxy and the existing masonry materials) to establish design criteria for acceptable anchorage along with a program for construction inspection and quality control, such as sampling and testing of a specified percentage of installed epoxy anchors. This is a good alternative for cases where it is necessary or desired to preserve the architectural features of the facade.

- **Partial reinforcement of existing masonry bearing walls.** It is possible to install new reinforced concrete on less than 100% of the existing masonry bearing walls if the following requirements are met: (1) new shear wall elements are designed to resist 100% of the specified horizontal seismic loads along each wall line; (2) new chords and collectors are designed to deliver 100% of the seismic loads to the new shear wall elements; and (3) unreinforced masonry bearing walls without concrete reinforcement are adequately protected from out-of-plane failure and loss of gravity load-carrying ability. Continuous installation of new reinforced concrete shear walls was recommended to protect masonry walls from damage and provide supplemental support for gravity loads. Protecting masonry walls from out-of-plane failure can be accomplished with other materials and methods, such as the use of steel elements spanning vertically between diaphragms (known as strongbacks). This method will require the use of imported structural steel materials and carefully engineered connections to deliver out-of-plane forces into each diaphragm. It also results in less protection to existing masonry walls and potentially less reliable performance in an earthquake.

Regardless of specific retrofit measures selected, all retrofit solutions must meet all requirements of these *Guidelines*, and must be engineered for each individual school building considering the conditions that are present at each site.

4.5 Seismic Retrofit of Typology D-1: Precast Concrete Frame

Typical Typology D-1 buildings are precast concrete frame structures, one to two stories tall, with a story height of 3.3 meters for classrooms (Figure 4-7) and 6.6 meters for gymnasiums (Figure 4-8). Typology D-1 buildings include a primary seismic and vertical load-carrying structure consisting of precast concrete beams, columns, and girders supporting precast concrete planks forming the floor and roof systems. Typical column modules are arranged in longitudinal and transverse grids measuring 6 meters. Precast concrete planks at the floor and roof have grouted joints, but lack a topping slab. The precast beams and columns are connected at their joints with the use of field-welded or lap-spliced connections between extended and exposed steel reinforcing bars. Exterior wall enclosures consist of precast concrete spandrel panels connected to the precast columns and beams with flexible bolted and welded connections. Interior partitions consist of unreinforced concrete panel or unreinforced masonry construction.

Typology D-1 schools are typically composed of multiple wings (buildings) with rectangular plans, connected by corridors, and separated by anti-seismic joints. Figure 4-9 illustrates a typical Typology D-1 school site consisting of four buildings connected by a single corridor structure. Figure 4-10 shows a corresponding wall layout that would be typical for two-story Typology D-1 school buildings.

Gymnasiums and auditoriums are typically long-span, open structures with tall stories existing as separate buildings or occupying portions of other buildings on a school site. Typology D-1 gymnasium and auditorium structures have tall precast concrete columns with precast perimeter roof beams supporting roof structures consisting of precast, prestressed concrete ribbed slabs spanning 12 meters.

Typology D-1 buildings are considered the predominant type of schools constructed in Armenia during the 1970-1988 pre-Spitak period, and were typically designed for minimal seismic forces (approximately 0.10g).

4.5.1 Seismic Deficiencies of Typology D-1 Buildings

Typology D-1 buildings depend on precast beam-column frame systems to resist earthquake forces. Precast frame systems are extremely sensitive to connection detailing, and have demonstrated poor performance in past earthquakes. Poorly detailed connections lack adequate strength and ductility to resist earthquake forces, which can result in loss of lateral load-carrying ability, loss of vertical support, and collapse of the frame system. Floor and roof systems consisting of precast concrete planks without cast-in-place topping slabs result in weak or inadequate diaphragms with limited ability to distribute loads to the elements of the seismic force-resisting system. Exterior precast wall panels, and interior unreinforced masonry partition walls have little capacity to resist in-plane and out-of-plane forces and

Figure 4-7 Typical two-story Typology D-1 classroom building.

Figure 4-8 Typical Typology D-1 gymnasium building.

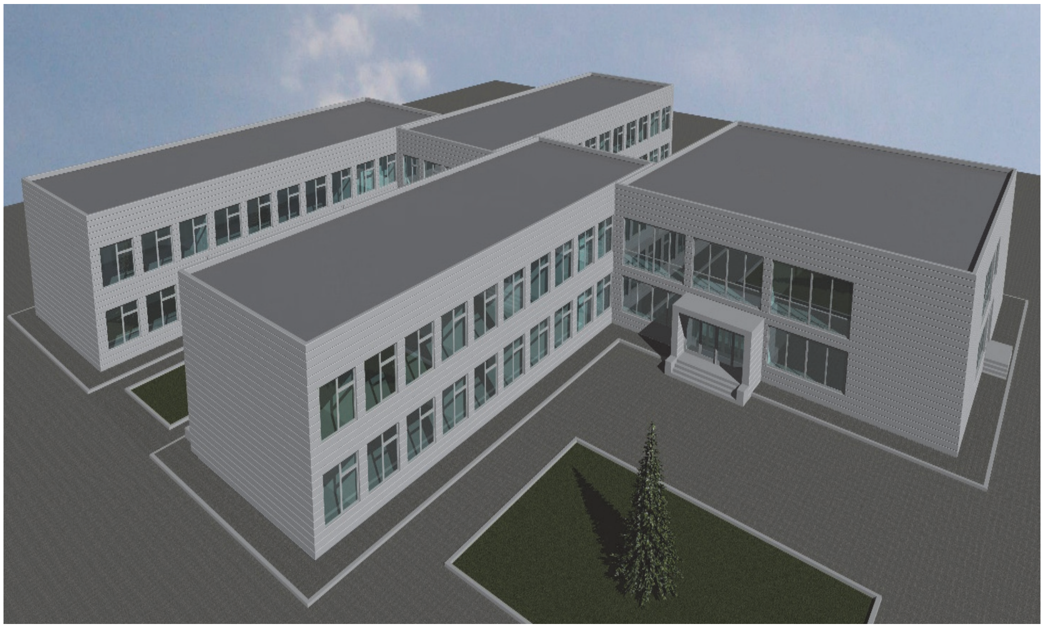


Figure 4-9 Typical Typology D-1 school site with four buildings separated by anti-seismic joints (EEC et al., 2015).

Figure 4-10 Typical wall layout for two-story Typology D-1 school buildings (EEC et al., 2015).

deformations associated with earthquakes, resulting in the potential for collapse of the walls and risk to the school population from falling hazards.

The following seismic deficiencies identified on the data collection and evaluation form are present in Typology D-1 buildings:

- precast concrete beam-column frame construction;
- weak/non-ductile precast concrete frame connections;
- roof and floor framing consisting of precast concrete planks without topping slabs;
- lack of positive connection between precast floor/roof planks and supporting building frames;
- inadequately anchored exterior precast wall panels;
- interior partition walls of unreinforced masonry or precast concrete construction; and
- anti-seismic joints filled with debris.

Many Typology D-1 school buildings also have additional vulnerabilities, such as poor quality materials, poor quality workmanship, and lack of maintenance.

4.5.2 Seismic Retrofit of Typology D-1 Buildings – Typical Classroom Building

This section presents a conceptual seismic retrofit scheme for a typical classroom building of Typology D-1 construction. Because of well-defined, repeatable physical characteristics, this conceptual design is generally applicable to Typology D-1 buildings with the same (or similar) characteristics. However, it is not a prescriptive engineering solution for any one specific building. As a result, implementation of this scheme to a specific building will require the involvement of an engineer to evaluate the applicability of the recommended solution to each individual school building and the conditions that are present at each existing school site.

This conceptual seismic retrofit scheme is applicable to 1970-1988 Typology D-1 classroom buildings, up to two stories in height, with precast concrete primary building frames and precast concrete floor and roof systems. Connecting structures, such as corridors between classroom wings, are not included in this scheme, but should be retrofitted with similar concepts using a similar engineering approach. This scheme was designed using the following assumptions:

- The school is located on a flat site (defined as a slope of 10% or less). Sloped sites are special cases that require additional engineering attention.
- The school is not located within 10 km of a fault. School sites located within 10 km of a fault must be designed for increased horizontal ground accelerations.

To eliminate seismic deficiencies in Typology D-1 typical classroom buildings, the following retrofit measures are recommended. A structural narrative describing the measures in more detail, along with conceptual plans and typical details are provided in Appendix C.

- To provide sufficient strength and stiffness to limit potential earthquake damage, the existing precast concrete building frame system should be supplemented with new reinforced concrete shear walls at selected locations. The new shear walls should be designed to take 100% of the specified in-plane seismic loads.
- To deliver seismic loads to new shear wall locations, new reinforced concrete collectors should be provided below the existing floor framing along all transverse and longitudinal shear wall lines. Use of existing precast beams and girders without supplemental reinforcement to resist collector forces is not permitted.
- The installation of new reinforced concrete shear walls and topping slabs will add significant additional gravity and seismic loads on existing foundations. To provide adequate strength and additional overturning resistance, existing foundations below new shear walls should be supplemented with new reinforced concrete. In cases where additional overturning stability is necessary, foundation reinforcement can be extended beyond shear wall locations as grade beams to engage additional dead load.
- To provide continuity for transferring all shear wall and collector forces through existing concrete elements, epoxy dowels extending through existing precast beams, precast columns, and foundation elements are necessary.
- To provide diaphragms for transferring seismic forces to the new elements of the seismic force-resisting system, new reinforced concrete topping slabs should be installed over existing precast planks at the floor and roof levels. Existing floor and roof surfaces must be prepared for the application of topping slabs through removal of floor finishes and roofing materials, and the cleaning and roughening of the exposed concrete surfaces.
- The thickness and strength of concrete, and size and spacing of reinforcement, must be engineered for each school building at each site. The following minimums were assumed in the design of the recommended scheme for typical classroom buildings:
    - Minimum thickness of concrete for shear walls: 30 cm.
    - Minimum thickness of concrete for topping slabs: 80 mm. Lightweight concrete may be used for topping slabs to reduce the added weight.
    - Minimum strength of concrete: 20 MPa (cylindrical strength).
    - Maximum spacing of reinforcing bars in shear walls and topping slabs: 15 cm each way.
    - Maximum allowable design shear capacity for new reinforced concrete shear walls: $0.7\sqrt{f'_c}$ [MPa].
- To facilitate the construction of new shear walls, existing exterior precast panels should be removed, and existing floor and roof framing should be temporarily shored as needed, at new wall locations.
- Exterior precast wall panels are anchored by welded and bolted connections to the supporting precast beams and columns. Concurrent with the removal of exterior precast wall panels at new shear wall locations, the adequacy and condition of the panels, connections, and supporting structure should be

inspected and evaluated. If the panels, connections, or supporting structure are not adequate to resist in-plane and out-of-plane seismic loads, and strengthening of the attachment is not feasible, all panels should be removed and replaced with modern lightweight cold-formed steel studs and curtain wall construction.

- At locations of new exterior shear walls, the architectural appearance of exterior wall surfaces should be replicated using modern lightweight cold-formed steel studs and curtain wall construction.
- If the new shear wall design requires the closure of existing windows, the need for minimum lighting and ventilation should be satisfied.
- To minimize seismic mass and potential falling hazards, all interior nonstructural unreinforced precast concrete and masonry partitions should be removed and replaced with modern lightweight cold-formed steel studs and gypsum wallboard construction.
- To allow individual buildings to move independently, avoid pounding damage, and prevent unintended torsional response, existing anti-seismic joints must be cleared of debris, widened to accommodate the expected seismic drifts, and protected to avoid future accumulation of debris.

4.5.3 Seismic Retrofit of Typology D-1 Buildings – Typical Gymnasium Building

This section presents a conceptual seismic retrofit scheme for a typical long-span, tall-story gymnasium building of Typology D-1 construction. This conceptual design is generally applicable to Typology D-1 gymnasium buildings with the same (or similar) characteristics, but is not a prescriptive engineering solution for any one specific building. Implementation of this scheme to a specific building will require engineering evaluation of the applicability of the recommended solution to each individual building and the conditions that are present at each existing school site.

To eliminate seismic deficiencies in Typology D-1 typical gymnasium buildings, the following retrofit measures are recommended. A structural narrative describing the measures in more detail, along with conceptual plans and typical details are provided in Appendix C.

- To provide sufficient strength and stiffness to limit potential damage, new reinforced concrete shear walls should be designed and constructed on each transverse and longitudinal wall line defining the tall one-story gymnasium portion, as well as the two-story mezzanine portion, of the building. The new reinforced concrete shear walls should be designed to take 100% of the specified in-plane seismic loads and should be sized to span for out-of-plane loading.
- To provide adequate diaphragms for building stability and for anchoring walls out-of-plane, a new reinforced concrete topping slab should be installed over the existing long-span, precast, prestressed concrete roof structure and the existing precast mezzanine floor structure. The ability of the existing roof and floor structures to support the additional gravity loads must be verified, or supplemental gravity support must be provided. The surface should be prepared for the application of a topping slab through removal of roofing materials, and the cleaning and roughening of the exposed concrete surface.

- To deliver seismic loads to new shear wall locations, new reinforced concrete collectors should be provided below the existing floor and roof framing. Use of existing precast beams and girders without supplemental reinforcement to resist collector forces is not permitted.
- The installation of new reinforced concrete shear walls and topping slabs will add significant additional gravity and seismic loads on existing foundations. To provide adequate strength and overturning resistance, existing foundations below new shear walls should be supplemented with new reinforced concrete.
- To provide continuity for transferring all shear wall and collector forces through existing concrete elements, epoxy dowels extending through existing precast beams, precast columns, and foundation elements are necessary.
- To facilitate the construction of new shear walls, existing exterior precast panels should be removed, and existing roof and floor structures should be temporarily shored as needed, at new wall locations.
- Exterior precast wall panels are anchored by welded and bolted connections to the supporting precast beams and columns. Concurrent with the removal of exterior precast wall panels at new shear wall locations, the adequacy and condition of the panels, connections, and supporting columns should be inspected and evaluated. If the panels, connections, or supporting columns are not adequate to resist in-plane and out-of-plane seismic loads, and strengthening of the attachment is not feasible, all panels should be removed and replaced with modern lightweight cold-formed steel studs and curtain wall construction.
- At locations of new exterior shear walls, the architectural appearance of exterior wall surfaces should be replicated using modern lightweight cold-formed steel studs and curtain wall construction.
- If the new shear wall design requires the closure of existing windows, the need for minimum lighting and ventilation should be satisfied.

4.5.4 Possible Alternative Seismic Retrofit Measures for Typology D-1 Buildings

The conceptual seismic retrofit solutions outlined in Section 4.5.2 and Section 4.5.3 have been recommended considering local Armenian design and construction practices, ease of design and construction, and reliability in achieving the required performance of school buildings in an earthquake. Use of alternative retrofit measures will affect constructability and estimated construction costs to varying degrees. This section presents alternative retrofit measures that could be considered for Typology D-1 buildings. Individual trade-offs for costs and benefits associated with the use of alternative retrofit measures should be considered on a case-by-case basis.

- **Use of additional new shear walls.** The number, location, and length of new shear walls affects the demands on the diaphragms, foundations, and walls themselves. In some cases it might be possible to reduce overall retrofit costs by providing additional shear wall locations that result in reduced thickness of required diaphragm strengthening, and a reduced amount of foundation strengthening required for overturning resistance.

- **Use of friction piles.** Depending on the number of shear walls and the resulting overturning demands, it might be possible to reduce foundation costs by providing friction piles for uplift resistance instead of grade beams and foundation strengthening to engage sufficient dead load to resist uplift.
- **Shear walls offset from the centerline of column grid lines.** Shear walls have been located on the centerline of column grid lines to most efficiently engage the existing framing for overturning resistance. This results in added complexity for shear wall and collector detailing, and the need for additional epoxy dowels to transfer forces through existing framing. Alternatively, shear walls could be offset from the centerline of column grid lines, which would simplify connection detailing, but would require additional consideration for engaging dead load for overturning resistance.

Regardless of specific retrofit measures selected, all retrofit solutions must meet all requirements of these *Guidelines*, and must be engineered for each individual school building considering the conditions that are present at each site.

4.6 Seismic Retrofit of Typology D-2: Precast Concrete Frame

Typical Typology D-2 buildings are precast concrete frame structures that are similar to Typology D-1 buildings, except they are three to four stories tall. Classrooms (Figure 4-11) have typical story heights of 3.3 meters, and gymnasiums have story heights as tall as 7.9 meters. Typology D-2 buildings include a primary seismic and vertical load-carrying structure consisting of precast concrete beams, columns, and girders supporting precast concrete planks forming the floor and roof systems. Typical column modules are arranged in longitudinal and transverse grids measuring 6 meters. Precast concrete planks at the floor and roof have grouted joints, but lack a topping slab. The precast beams and columns are connected at their joints with the use of field-welded or lap-spliced connections between extended and exposed steel reinforcing bars. Exterior wall enclosures consist of precast concrete spandrel panels connected to the precast columns and beams with flexible bolted and welded connections. Interior partitions consist of unreinforced concrete panel or unreinforced masonry construction.

Typology D-2 schools are composed of multiple wings (buildings) with rectangular plans, connected by corridors, and separated by anti-seismic joints. Figure 4-12 illustrates a typical Typology D-2 school site consisting of two buildings connected by a corridor structure. Figure 4-13 shows a corresponding wall layout that would be typical for Typology D-2 school buildings.

Typology D-2 gymnasiums and auditoriums are essentially identical to Typology D-1, consisting of tall precast concrete columns with precast perimeter roof beams supporting roof structures consisting of precast, prestressed concrete ribbed slabs spanning 12 meters.

Typology D-2 buildings (along with Typology D-1 buildings) are considered the predominant type of schools constructed in Armenia during the 1970-1988 pre-Spitak period, and were typically designed for minimal seismic forces (approximately 0.10g).

4.6.1 Seismic Deficiencies of Typology D-2 Buildings

Given their similarity to Typology D-1 buildings, Typology D-2 buildings contain the same basic seismic deficiencies. Typology D-2 buildings depend on precast beam-column frame systems to resist earthquake forces, which are extremely sensitive to connection detailing, and have demonstrated poor performance in past earthquakes. Poorly detailed connections lack adequate strength and ductility to resist earthquake forces, which can result in loss of lateral load-carrying ability, loss of vertical support, and collapse of the frame system. Floor and roof systems consisting of precast concrete planks without cast-in-place topping slabs result in weak or inadequate diaphragms with limited ability to distribute loads to the elements of the seismic force-resisting system. Exterior precast wall panels, and interior unreinforced masonry partition walls have little capacity to resist in-plane and out-of-plane forces and deformations associated with earthquakes, resulting in the potential for collapse of the walls and risk to the school population from falling hazards. The following seismic deficiencies identified on the data collection and evaluation form are present in Typology D-2 buildings:

- precast concrete beam-column frame construction;
- weak/non-ductile precast concrete frame connections;
- roof and floor framing consisting of precast concrete planks without topping slabs;
- lack of positive connection between precast floor/roof planks and supporting building frames;
- inadequately anchored exterior precast wall panels;
- interior partition walls of unreinforced masonry or precast concrete construction; and
- anti-seismic joints filled with debris.

Figure 4-11 Typical four-story Typology D-2 classroom building.

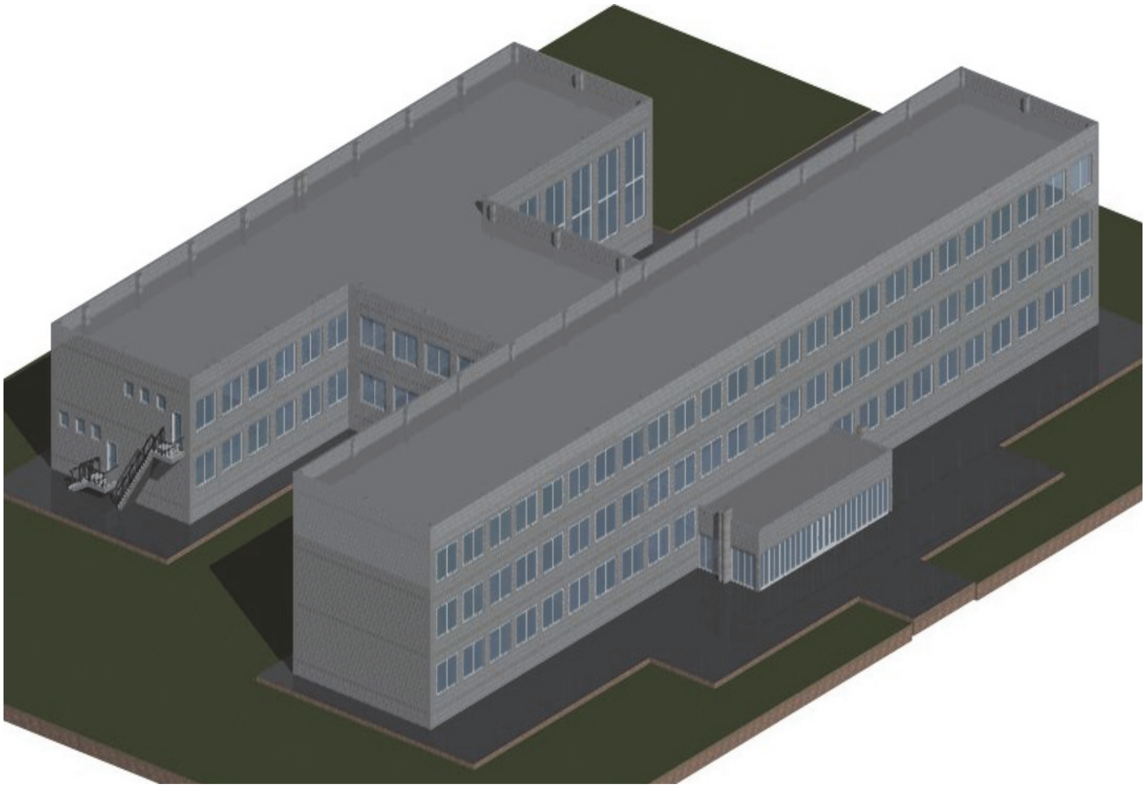


Figure 4-12 Typical Typology D-2 school site with two buildings connected by a corridor structure (EEC et al., 2015).

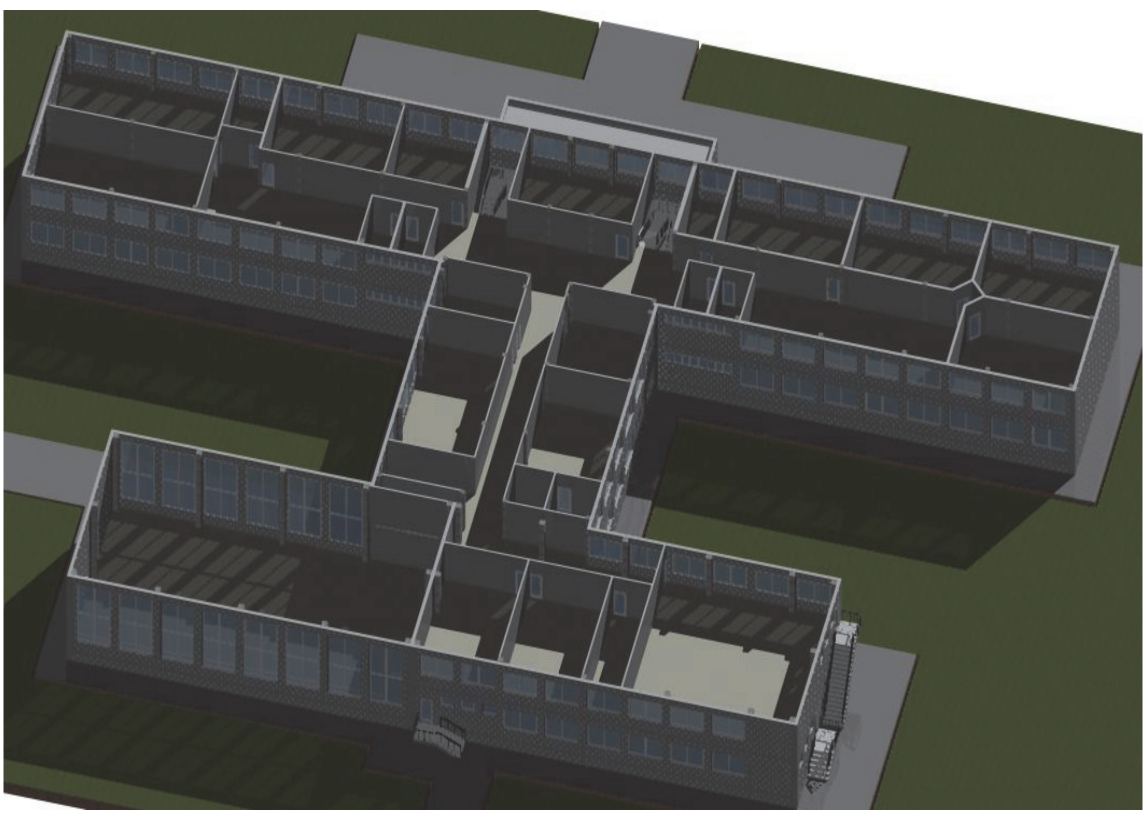


Figure 4-13 Typical wall layout for Typology D-2 school buildings (EEC et al., 2015).

In addition, some Typology D-2 buildings are four stories tall. In Section 7.3.7 in RABC II-6.02-2006, school buildings are limited to three stories in height, so four-story Typology D-2 buildings should not be considered for retrofit unless the upper stories are removed. Typology D-2 school buildings also have additional vulnerabilities, such as poor quality materials, poor quality workmanship, and lack of maintenance.

4.6.2 Seismic Retrofit of Typology D-2 Buildings – Typical Classroom Building

This section presents a conceptual seismic retrofit scheme for a typical classroom building of Typology D-2 construction. This conceptual design is similar to the design for Typology D-1 construction. Because of well-defined, repeatable physical characteristics, it is generally applicable to Typology D-2 buildings with the same (or similar) characteristics. However, it is not a prescriptive engineering solution for any one specific building. As a result, implementation of this scheme to a specific building will require the involvement of an engineer to evaluate the applicability of the recommended solution to each individual school building and the conditions that are present at each existing school site.

This conceptual seismic retrofit scheme is applicable to 1970-1988 Typology D-2 classroom buildings, up to three stories in height, with precast concrete primary building frames and precast concrete floor and roof systems. Connecting structures, such as corridors between classroom wings, are not included in this scheme, but should be retrofitted with similar concepts using a similar engineering approach. This scheme was designed using the following assumptions:

- The school is located on a flat site (defined as a slope of 10% or less). Sloped sites are special cases that require additional engineering attention.
- The school is not located within 10 km of a fault. School sites located within 10 km of a fault must be designed for increased horizontal ground accelerations.

To eliminate seismic deficiencies in Typology D-2 typical classroom buildings, the following retrofit measures are recommended. They are similar to Typology D-1 retrofit measures, but differ in terms of the quantity and details of the work because of additional seismic demands associated with taller structures. A structural narrative describing the measures in more detail, along with conceptual plans and typical details are provided in Appendix D.

- To provide sufficient strength and stiffness to limit potential earthquake damage, the existing precast concrete building frame system should be supplemented with new reinforced concrete shear walls at selected locations. The new shear walls should be designed to take 100% of the specified in-plane seismic loads, and should consider the need for boundary zone reinforcement based on shear wall requirements in ACI 318-11 (ACI, 2011).
- To deliver seismic loads to new shear wall locations, new reinforced concrete collectors should be provided below the existing floor framing along all transverse and longitudinal shear wall lines. Use of existing precast beams and girders without supplemental reinforcement to resist collector forces is not permitted.

- The installation of new reinforced concrete shear walls and topping slabs will add significant additional gravity and seismic loads on existing foundations. To provide adequate strength and additional overturning resistance, existing foundations below new shear walls should be supplemented with new reinforced concrete. In cases where additional overturning stability is necessary, foundation reinforcement can be extended beyond shear wall locations as grade beams to engage additional dead load.
- To provide continuity for transferring all shear wall and collector forces through existing concrete elements, epoxy dowels extending through existing precast beams, precast columns, and foundation elements are necessary.
- To provide diaphragms for transferring seismic forces to the new elements of the seismic force-resisting system, new reinforced concrete topping slabs should be installed over existing precast planks at the floor and roof levels. Existing floor and roof surfaces must be prepared for the application of topping slabs through removal of floor finishes and roofing materials, and the cleaning and roughening of the exposed concrete surfaces.
- The thickness and strength of concrete, and size and spacing of reinforcement, must be engineered for each school building at each site. The following minimums were assumed in the design of the recommended scheme for Typology D-2 typical classroom buildings:
    - Minimum thickness of concrete for shear walls: 30 cm.
    - Minimum thickness of concrete for topping slabs: 80 mm. Lightweight concrete may be used for topping slabs to reduce the added weight.
    - Minimum strength of concrete: 20 MPa (cylindrical strength).
    - Maximum spacing of reinforcing bars in shear walls and topping slabs: 15 cm each way.
    - Maximum allowable design shear capacity for new reinforced concrete shear walls: $0.7\sqrt{f'_c}$ [MPa].
    - Provision for minimum typical boundary zone reinforcement provided at the ends of all shear walls based on requirements in ACI 318-11 (ACI, 2011).
- To facilitate the construction of new shear walls, existing exterior precast panels should be removed, and existing floor and roof framing should be temporarily shored as needed, at new wall locations.
- Exterior precast wall panels are anchored by welded and bolted connections to the supporting precast beams and columns. Concurrent with the removal of exterior precast wall panels at new shear wall locations, the adequacy and condition of the panels, connections, and supporting structure should be inspected and evaluated. If the panels, connections, or supporting structure are not adequate to resist in-plane and out-of-plane seismic loads, and strengthening of the attachment is not feasible, all panels should be removed and replaced with modern lightweight cold-formed steel studs and curtain wall construction.
- At locations of new exterior shear walls, the architectural appearance of exterior wall surfaces should be replicated using modern lightweight cold-formed steel studs and curtain wall construction.

- If the new shear wall design requires the closure of existing windows, the need for minimum lighting and ventilation should be satisfied.
- To minimize seismic mass and potential falling hazards, all interior nonstructural unreinforced precast concrete and masonry partitions should be removed and replaced with modern lightweight cold-formed steel studs and gypsum wallboard construction.
- To allow individual buildings to move independently, avoid pounding damage, and prevent unintended torsional response, existing anti-seismic joints must be cleared of debris, widened to accommodate the expected seismic drifts, and protected to avoid future accumulation of debris.

4.6.3 Seismic Retrofit of Typology D-2 Buildings – Typical Gymnasium Building

Typology D-2 gymnasiums and auditoriums are essentially identical to Typology D-1 gymnasiums and auditoriums. As a result, the retrofit measures to eliminate seismic deficiencies in Typology D-2 gymnasium buildings are the same as specified for Typology D-1 in Section 4.5.3 and Appendix C of these *Guidelines*.

4.6.4 Possible Alternative Seismic Retrofit Measures for Typology D-2 Buildings

The conceptual seismic retrofit solutions outlined in Section 4.6.2 have been recommended considering local Armenian design and construction practices, ease of design and construction, and reliability in achieving the required performance of school buildings in an earthquake. Use of alternative retrofit measures will affect constructability and estimated construction costs to varying degrees. This section presents alternative retrofit measures that could be considered for Typology D-2 buildings. Individual trade-offs for costs and benefits associated with the use of alternative retrofit measures should be considered on a case-by-case basis.

- **Use of additional new shear walls.** The number, location, and length of new shear walls affects the demands on the diaphragms, foundations, and walls themselves. In some cases it might be possible to reduce overall retrofit costs by providing additional shear wall locations that result in reduced thickness of required diaphragm strengthening, a reduced amount of foundation strengthening required for overturning resistance, and elimination of the need for boundary zone reinforcement at the ends of all shear walls based on requirements in ACI 318-11 (ACI, 2011).
- **Use of friction piles.** Depending on the number of shear walls and the resulting overturning demands, it might be possible to reduce foundation costs by providing friction piles for uplift resistance instead of grade beams and foundation strengthening to engage sufficient dead load to resist uplift.
- **Shear walls offset from the centerline of column grid lines.** Shear walls have been located on the centerline of column grid lines to most efficiently engage the existing framing for overturning resistance. This results in added complexity for shear wall and collector detailing, and the need for additional epoxy dowels to transfer forces through existing framing. Alternatively, shear walls could be offset from the centerline of column grid lines, which would simplify connection detailing, but would require additional consideration for engaging dead load for overturning resistance.

Regardless of specific retrofit measures selected, all retrofit solutions must meet all requirements of these *Guidelines*, and must be engineered for each individual school building considering the conditions that are present at each site.

Chapter 5

Design of New School Buildings

This chapter provides recommended seismic design requirements that are generally applicable to new school buildings in Armenia. Because the United Nations Development Programme (UNDP) is developing a new model for school construction in Armenia, a conceptual seismic design for new school buildings is presented, based on the standard modular construction currently being developed under that program.

5.1 General Seismic Design Requirements for New School Construction

Because of their occupancy and importance, new school buildings have an elevated expectation of performance, both in Armenia, and internationally. The general seismic design approach is intended to limit damage in school buildings to certain specified levels.

To achieve limited damage as a performance objective, the recommended seismic design approach is to provide adequate strength to resist earthquake forces, and adequate stiffness to limit building movement (drift) in an earthquake. To provide a higher level of confidence in achieving the required performance objective, a conservative design approach along with certain simplifying assumptions are made to minimize some of the variability and uncertainty that can be associated with seismic design. The following sections provide requirements deemed necessary for seismic designs to meet the specified Armenian performance objectives for schools, consistent with international standards and best practices for earthquake-resistant design in regions of high seismicity around the world.

5.1.1 Building Code and Construction Norms

Seismic design of new school buildings should conform to the requirements of the Republic of Armenia Building Code, RABC II-6.02-2006 (Ministry of Urban Development, 2006), and Construction Norms of the Republic of Armenia, CNRA 20-06-2014 (Ministry of Urban Development, 2014), as modified by these *Guidelines*.

5.1.2 Material Design Standards

Reinforced concrete design and construction used in design of new school buildings should conform to SNiP 2.03.01-84*, *Concrete and Reinforced Concrete Structures* (SNIP, 1984), with the following additional specific requirements based on requirements in ACI 318-11 (ACI, 2011):

- Minimum concrete strength (unless otherwise noted): 20 MPa (cylindrical strength); this corresponds to B30 concrete.

- Minimum reinforcement steel strength: 500 MPa. It is recommended to use grade A500C for all steel reinforcement. All reinforcing bars should be deformed. Smooth or twisted bars are not permitted.
- Lap splices in reinforcement should not be less than 40 bar diameters for concrete in compression, and 60 bar diameters for concrete in tension, but not less than 60 cm as a minimum.

5.1.3 Seismic Zone and Site Classification

For design of new school buildings, it is recommended that all locations be considered Seismic Zone 3, which is the highest seismic hazard in Armenia. Soil Category III should be assumed for the purposes of calculating seismic loads.

School construction is prohibited on sites that are considered unfavorable for construction per Section 5.4.1 in RABC II-6.02-2006, or on Soil Category IV per Section 7.14 in RABC II-6.02-2006, and the slope on the site should not be over 15 degrees.

5.1.4 Seismic Analysis Procedure

Seismic retrofit designs may be based on equivalent lateral force procedures and linear analysis techniques. Section 6.4.1 in RABC II-6.02-2006 provides the equation for calculating horizontal seismic loads for design. For seismic design of new school buildings, the following values should be used:

- The soil factor, k_o, should be taken as 1.1 (per Table 4 in RABC II-6.02-2006, assuming Seismic Zone 3 and Soil Category III).
- The permissible damage coefficient, k_1, should be taken from Table 7 in RABC II-6.02-2006 assuming Seismic Zone 3. See Section 5.1.11 for schools that are intended to serve as emergency shelters.
- The importance coefficient, k_2, should be taken as 1.3 for schools, per Table 8 in RABC II-6.02-2006. See Section 5.1.11 for schools that are intended to serve as emergency shelters.
- The soil-structure interaction coefficient, k_3, should have a value of 0.7 or greater per Section 6.8.2 in RABC II-6.02-2006.
- The dimensionless coefficient of seismicity, A, should be 0.4, consistent with the assumption of Seismic Zone 3.
- The dimensionless dynamic coefficient, β, should be taken as 2.5.
- For sites within 10 km of known mapped faults, horizontal ground acceleration values should be multiplied by 1.2 per Section 5.2.2 in RABC II-6.02-2006.

5.1.5 New Construction Design Requirements

New elements of the seismic force-resisting system should be designed to resist 100% of the calculated horizontal seismic loads. The seismic force-resisting system should be symmetric to the extent possible and the design should explicitly account for any difference between the center of mass and center of rigidity.

Connections between elements of the seismic force-resisting system should be detailed to provide ductility, allow for the expected movement (drift), and be designed develop the capacity of the connected members, where possible.

Period limitations in Section 7.1.8 of RABC II-6.02-2006 may be neglected for design of new school buildings. These provisions are important for avoiding resonance in tall buildings on soft soil sites, and become less important for low-rise buildings on typical soil sites.

5.1.6 Limitations on Number of Stories

New school buildings are limited to three stories in height per Section 7.3.7 in RABC II-6.02-2006. Basements that are more than 50% above grade are considered a story.

5.1.7 Drift Limits

Drift limits should conform to values provided per Table 7 in RABC II-6.02-2006. Drifts should be calculated using actual earthquake loads before reduction to account for system ductility. Designs should provide sufficient stiffness so that damage is limited to Damage Extent 1 or Damage Extent 2, depending upon whether or not the facility will be used as an emergency shelter.

5.1.8 Diaphragms, Collectors, and Connections

Floor and roof diaphragms are necessary to anchor out-of-plane forces and distribute seismic loads throughout the building.

Collectors should be designed to adequately deliver loads to the vertical elements of the seismic force-resisting system.

Positive attachment for out-of-plane forces in accordance with Section 6.12 in RABC II-6.02-2006 should be provided between the diaphragms and all vertical elements in the building.

Anti-seismic joints should be provided to separate buildings at locations of plan irregularity. Anti-seismic joints should be sized to provide adequate separation for avoiding pounding or induced torsional responses in the structure.

5.1.9 Foundations

Foundations of new buildings should be placed on similar competent soils. If portions of a building will be founded on different soil types, the portions of the building on different soils should be separated by anti-seismic joints.

Isolated spread footings and grade beams should be tied together with a reinforced concrete slab-on-grade or reinforced concrete tie beams in both directions. Foundations under new shear walls should be checked for overturning stability. For short (or non-continuous) shear walls, new grade beams or friction piles may be necessary for overturning resistance to prevent rocking. Friction piles may only be used to resist uplift, not for vertical bearing, per Section 7.4 in RABC II-6.02-2006.

Additional design requirements for foundations provided in Section 7.4 of RABC II-6.02-2006 should also be followed. Rubble concrete foundations or basement walls are not permitted.

5.1.10 Nonstructural Considerations

Interior nonstructural partitions and exterior closure walls should consist of modern lightweight materials, such as cold-formed steel studs with gypsum wallboard finishes, to minimize seismic demands and eliminate potential falling hazards that would be associated with traditional masonry partitions.

Masonry and precast veneers are strongly discouraged because they pose a serious falling hazard and safety risk if not properly anchored. If masonry veneer is used, it should be positively anchored (with anchors, not grout or other bonded attachments) to engineered walls that are positively attached to the structure. Bonded masonry veneer systems are not permitted for new school construction.

Equipment, parapets, nonstructural walls, suspended piping, and service lines that pose a falling hazard should be braced and positively anchored to the structure per Section 6.12 and Section 7.1.9 of RABC II-6.02-2006. Chapter 6 in these *Guidelines* provides specific recommendations for anchoring and bracing nonstructural components that are commonly found in school buildings in Armenia.

5.1.11 Special Requirements for Schools Serving as Emergency Shelters

Schools that will serve as temporary emergency shelters after an earthquake must conform to Damage Extent 1, light damage to non-bearing elements, per RABC II-6.02-2006. For seismic design of new school buildings serving as emergency shelters, the following values should be used:

- The permissible damage coefficient, k_1, should be taken as 1.0.
- The importance coefficient, k_2, should be taken from Table 8 in RABC II-6.02-2006; however, this table does not explicitly specify an importance coefficient for emergency shelters. It is recommended that k_2 should not be taken as less than 1.30 for emergency shelters in school buildings.

Use of seismic force-resisting systems that limit drift are highly recommended for schools that will serve as emergency shelters (see Section 5.3). In addition, to serve as emergency shelters, important building systems must be braced and anchored to protect them from damage. Architectural finishes along with mechanical, electrical, and plumbing systems must allow for continued operation. Otherwise, provisions for emergency power, on-site water storage, and sanitation must be provided. Chapter 6 provides more guidance on properly securing nonstructural components.

5.2 Acceptable and Prohibited Types of Construction

Acceptable structural materials and systems include engineered cast-in-place reinforced concrete, reinforced concrete masonry units (CMU), and structural steel. Foundations should be constructed using reinforced concrete. To minimize seismic demands and eliminate potential falling hazards that would be associated with traditional masonry construction, acceptable construction for interior partitions consists of lightweight steel studs and gypsum wallboard. Similarly, acceptable construction for exterior closure walls consists of lightweight steel studs with exterior waterproof finishes, insulation, and interior gypsum wallboard surfaces.

Prohibited structural materials and systems include unreinforced masonry bearing walls or partition walls, and precast concrete frame systems with welded beam-column connections. Unreinforced masonry or rubble foundations are similarly prohibited. Use of precast plank floor and roof framing without a reinforced concrete topping slab is not permitted. Bonded masonry veneer exterior facades should be avoided.

5.3 Conceptual Seismic Design for New School Buildings

This section presents a conceptual seismic design scheme for new modular school construction based on prototypical model schools currently being developed under the United Nations Development Programme (UNDP). This conceptual scheme, however, is not a prescriptive engineering solution for any one specific building. As a result, implementation of this scheme to specific buildings will require the involvement of an engineer to evaluate the applicability of the recommended solution to each new school building and the conditions that are present at each school site.

The first floor plan for the UNDP prototypical model school is shown in Figure 5-1. This plan does not necessarily reflect the final design that will be prepared by UNDP, and is provided for conceptual design purposes only. As currently envisioned, the prototype has classroom modules for site and capacity adaptation. The classroom modules are two stories in height, while adjacent auditoriums and gymnasiums are tall, one-story, long-span structures with double-height stories.

The recommended lateral system for resisting seismic and wind loads for all new school construction, including classrooms, auditoriums, gymnasiums, and interconnecting structures is reinforced concrete shear walls. Reinforced concrete shear walls are recommended for new school construction because:

- Historically, reinforced concrete shear wall construction has performed well in earthquakes.
- Shear wall construction has a history of being used in Armenia for important structures, and can be constructed using locally available materials and a locally trained workforce.
- Redundant shear wall designs are relatively forgiving, and better able to accommodate construction deficiencies that might get missed during the inspection process.
- Shear walls provide the necessary strength and stiffness to limit potential damage in an earthquake, and allow for re-occupancy following an earthquake.
- Shear wall systems limit building movement in an earthquake so that school buildings with different story heights, such as classrooms and gymnasiums, are better able to be located adjacent to one another, without excessively large anti-seismic joints, and without the potential for damage due to pounding.

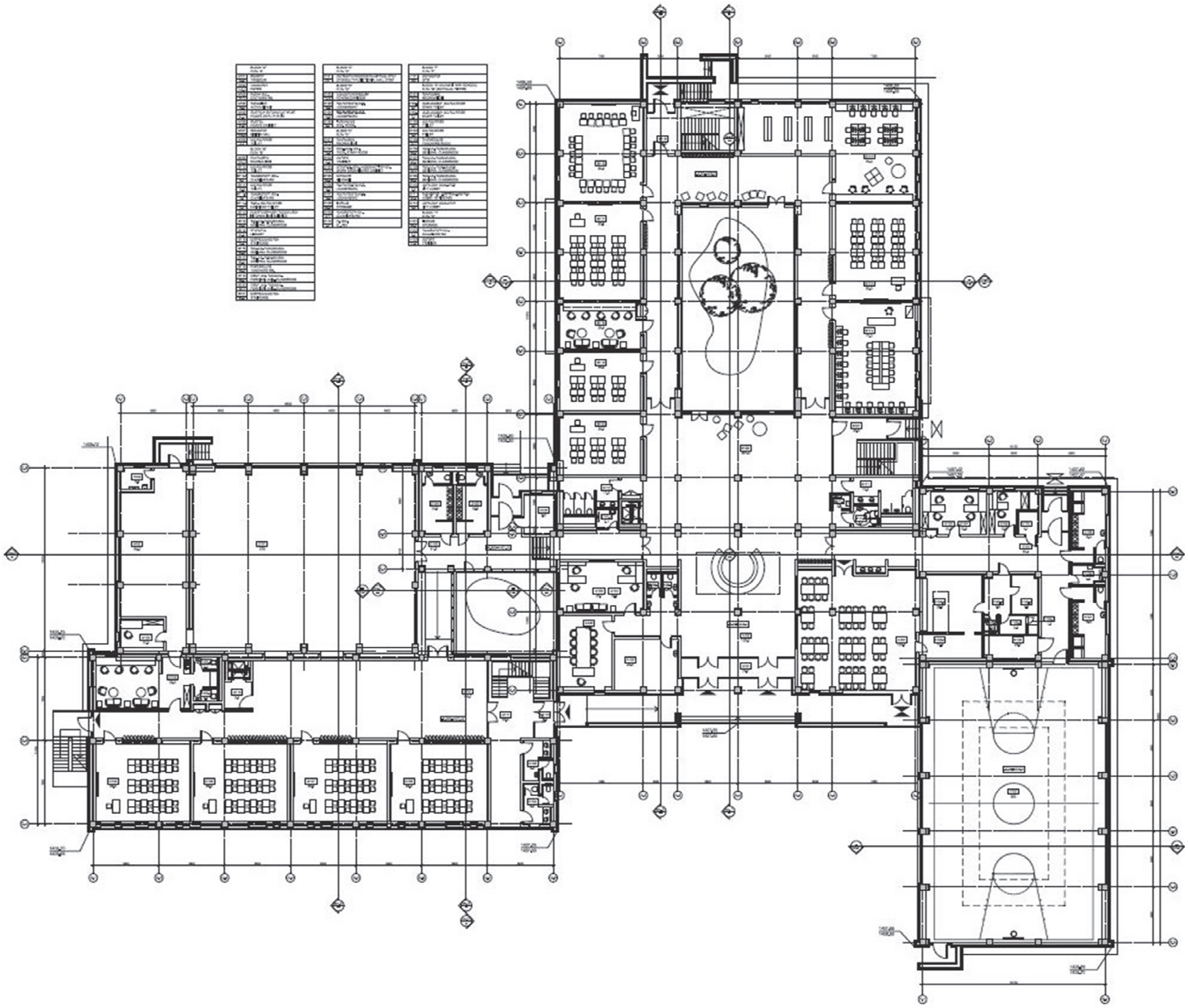


Figure 5-1 Ground floor plan of UNDP prototypical model school.

To achieve limited damage as a performance objective, provide adequate strength to resist earthquake forces, and provide adequate stiffness to limit building movement (drift) in an earthquake, the following seismic design measures are recommended. Conceptual plans and typical details for seismic design of new school buildings are provided in Appendix E.

- All modules should be separated by anti-seismic joints, and each module should have a separate, independent, and complete structural system (Figure E-1).
- The structural system should consist of cast-in-place reinforced concrete frames to support gravity loads, with cast-in-place reinforced concrete shear walls to resist horizontal earthquake loads (Figure E-2). Shear walls should be assumed non-load-bearing, but integral with the reinforced concrete frame.
- Shear walls should be placed in one-bay increments, between selected columns, located at or near the boundary of each floor or roof diaphragm, distributed on wall lines along four sides, with intermediate wall lines as dictated by the needs of the diaphragm design. The exact location of shear

walls can be based on architectural requirements, but they must form a complete and balanced system that is not subject to significant torsion (Figure E-3).

- The gravity columns should be aligned from foundation to roof, and designed to carry all building dead and live loads to the foundation level. Column reinforcing should include closely spaced hoops or ties around longitudinal reinforcing bars to provide for ductility.
- Floor and roof framing should consist of reinforced concrete one-way slabs on beams cast monolithically with the columns, or two-way slabs supported on columns. In a slab-column system, thickened slabs and provisions for shear transfer, such as bent stirrups, should be used at slab-column connections to prevent the potential for punching shear failure.
- For tall, open, long-span modules, such as auditoriums and gymnasiums, the roof structure should consist of steel trusses supported on reinforced concrete columns. Lightweight steel decking reinforced with horizontal steel bracing for diaphragm strength should be used to span between the trusses. Shear walls between the high roof and the foundation should be located around the perimeter (Figure E-4).
- Shear walls should be designed to resist 100% of the specified horizontal earthquake loads and detailed for ductility. Shear wall design and detailing should satisfy the following criteria (based on similar requirements provided in ACI 318 (ACI, 2011)):
    - Minimum shear wall thickness should be the greater of 200 mm or $h/30$, with h corresponding to the story height.
    - Minimum of two layers of vertical and horizontal reinforcing should be provided in walls, with a maximum spacing of 300 mm (Figure E-5).
    - Minimum area of horizontal reinforcement provided should be 0.25% of gross area of the vertical section.
    - Horizontal wall reinforcement should be fully developed into the building columns, which can serve as boundary elements for the shear walls. Columns that serve as boundary elements for shear walls should be designed for a combination of dead, live, and seismic loads (Figure E-7).
    - Steel reinforcement in boundary columns should be confined with tightly spaced hoops per Section 7.11.12 in RABC II-6.02-2006 (and not less than 100 mm maximum spacing at top and bottom 1/6 of column height) to prevent buckling under compressive loads. The reinforcement should be designed to ensure yielding prior to crushing of concrete.
- Shear walls should be designed to limit drifts per Table 7 of RABC II-6.02-2006, and should remain stable for overturning when fully loaded. Assuming a level building site (slope less than 15 degrees) and competent soils at shallow depth, the foundations should consist of a grid of continuous grade beams connecting reinforced concrete columns and walls, sized to support building dead, live, seismic, and wind loads (Figure E-6).
- Interior nonstructural walls should be modern, lightweight steel stud construction with gypsum wallboard finishes.

- Exterior closure walls should consist of insulated double wall construction using steel studs, exterior weather-resistant finishes, and interior gypsum wallboard. Any attached veneers should be positively anchored to the wall studs, which should be designed to take the increased load (Figure E-9).
- The design should provide for positive anchorage of relevant nonstructural components per Section 6.12.1 and Section 7.1.9 in RABC II-6.02-2006, and Chapter 6 in these *Guidelines*.

5.4 Possible Alternative Seismic Design Measures for New School Buildings

The conceptual seismic design solution outlined in Section 5.3 was developed considering local Armenian design and construction practices, ease of design and construction, and reliability in achieving the required performance of school buildings in an earthquake. Use of alternative seismic design measures will affect constructability and construction costs to varying degrees. This section presents alternative retrofit measures that could be considered. Individual costs and benefits associated with the use of alternatives should be considered on a case-by-case basis.

- **Use of engineered concrete masonry unit (CMU) shear walls in lieu of reinforced concrete shear walls.** Engineered, reinforced masonry shear walls can be considered if the following requirements are met: (1) the CMU shear walls are reinforced and fully grouted; (2) the CMU shear walls are constructed concurrently with cast-in-place reinforced concrete columns, beams, and slabs (not "in-filled" at a later time); (3) the CMU shear walls are properly connected to the reinforced concrete framing with dowels; and (4) the CMU shear walls are constructed with continuous inspection.
- **Use of reinforced concrete moment frames in one-story buildings.** The use of reinforced concrete moment frames could be considered in one-story buildings. In this case, one-story refers to one-story halls, classrooms, or auxiliary school buildings, but excludes one-story structures with tall story heights, such as gyms, auditoriums, cafeterias, and other high-occupancy or special structures. Reinforced concrete shear walls were recommended for simplicity and ease of use. Reinforced concrete moment frame systems will require the use of special seismic detailing, and additional inspection of critical placement of reinforcing bars during construction. Frame systems will experience more drift, resulting in greater potential for damage to deformation sensitive mechanical, electrical, and plumbing systems, and pounding with adjacent buildings.

Chapter 6
Nonstructural Components

This chapter provides examples of nonstructural bracing and anchorage details, based on international standards and best practices, which can be used as a basis for design and detailing of nonstructural components for schools in Armenia.

6.1 Requirements for Nonstructural Components

Seismic retrofit of existing school buildings and design of new school buildings should incorporate seismic anchorage calculations and details for nonstructural components, as specified in Section 6.12 of RABC II-6.02-2006. For schools that will serve as emergency shelters, all nonstructural components that are essential for school operation should be properly anchored and braced.

Equipment, parapets, nonstructural walls, suspended piping, and service lines that pose a falling hazard should be positively anchored and braced to the foundation, floor, or wall structures in accordance with RABC II-6.02-2006. Provisions should be made to allow for relative movement in suspended piping systems and heating systems, especially at locations of anti-seismic joints, as provided in Section 7.7 of RABC II-6.02-2006.

6.1.1 Nonstructural Components Relevant to Existing Schools

Existing schools in Armenia have nonstructural components that should be explicitly addressed in seismic retrofit designs. Some components will be part of the existing construction, and others might be installed as part of the retrofit. Nonstructural component that should be addressed in seismic retrofit designs include: light fixtures; non-bearing partitions; parapets; masonry veneers; heating, ventilating, and air-conditioning (HVAC) equipment; water heaters; natural gas or propane tanks; emergency power generators; wall-mounted equipment; and tall furnishings such as bookshelves or filing cabinets.

6.1.2 Nonstructural Components Relevant to New Schools

New school construction in Armenia should address all of the nonstructural components listed for retrofit of existing schools in Section 6.1.1, except that new school construction should not include unreinforced masonry parapets, masonry partition walls, or bonded veneers. In addition, new school designs are likely to include elevators, which must be addressed in the new school design. Suspended ceilings must also be addressed, if incorporated in the architectural design, but it is recommended to simply avoid the use of suspended ceilings in new school buildings.

For school buildings that will be used as emergency shelters, it is essential that critical systems necessary for operation are protected, otherwise provisions for systems such as emergency power, on-site water storage, and sanitation must be provided.

Emergency power generators should be properly installed and protected to ensure their functionality immediately following an earthquake. It is important to also have an adequate fuel supply in a protected area. Emergency power and fuel supply should be sufficient to operate lighting, security systems, and communication systems until full service is re-established. For guidance on best practices for ensuring emergency power in critical facilities, see FEMA P-1019, *Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability* (FEMA, 2014).

Nonstructural partitions in schools that will serve as emergency shelters should be constructed in a way that limits their potential damage and allows for continued occupancy following an earthquake. For an example of nonstructural considerations in schools designed as emergency shelters, see *Beaverton School District Resilience Planning for High School at South Cooper Mountain and Middle School at Timberland* (SEFT Consulting Group, 2015).

6.2 Architectural Components

Architectural components that may be applicable to school construction in Armenia are covered in the following sections.

6.2.1 Suspended Ceilings and Light Fixtures

Suspended ceilings are not typically used in existing buildings, however, they might be used in new school construction. The use of suspended ceilings in new school buildings is discouraged, but if they are provided, lateral and compression bracing must be installed. Figure 6-1 illustrates example bracing example for suspended ceiling systems. If suspended ceilings are used in schools that will be used as emergency shelters, adequate bracing should be applied at a spacing of not more than 2.5 meters by 3.7 meters (California Department of General Services, 2009). More details addressing other types of ceiling systems can be found in Section 6.3.4 of FEMA E-74 (FEMA, 2012).

Light fixtures may be included in new school buildings and could be added as part of a retrofit plan. Figure 6-2 provides an example of vertical support for light fixtures that weigh 4.5 kg to 25 kg and are a part of a seismically braced suspended ceiling system. Light fixtures within this weight range that are supported by the ceiling grid must have two safety wires attached to the fixture and the structure above. Light fixtures weighing over 25 kg must be supported directly from the floor/roof structure with adequate hangers. More details addressing other types of light fixtures can be found in Section 6.4.9 of FEMA E-74 (FEMA, 2012).

6.2.2 Nonstructural Interior Walls and Partitioning

Seismic retrofit designs should include the replacement of heavy partitions with modern lightweight partitions. Similarly, new school construction should use only lightweight partitions. Lightweight partitions must be attached to the structure for vertical and lateral (out-of-plane) support. For schools that will be used as emergency shelters (Damage Level 1 per Table 24 in RABC II-6.02-2006), installation details should allow for lateral drift of the structure without significant damage to partitions. This is particularly important if moment frame construction is used.

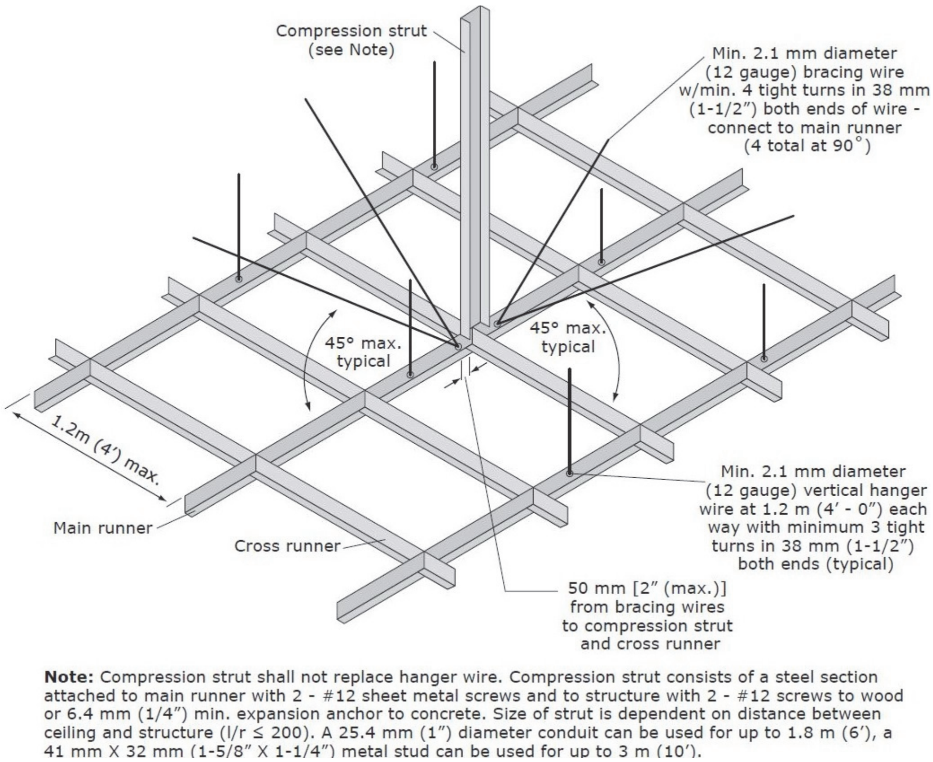


Figure 6-1 Example of bracing for suspended ceilings (adapted from FEMA, 2012).

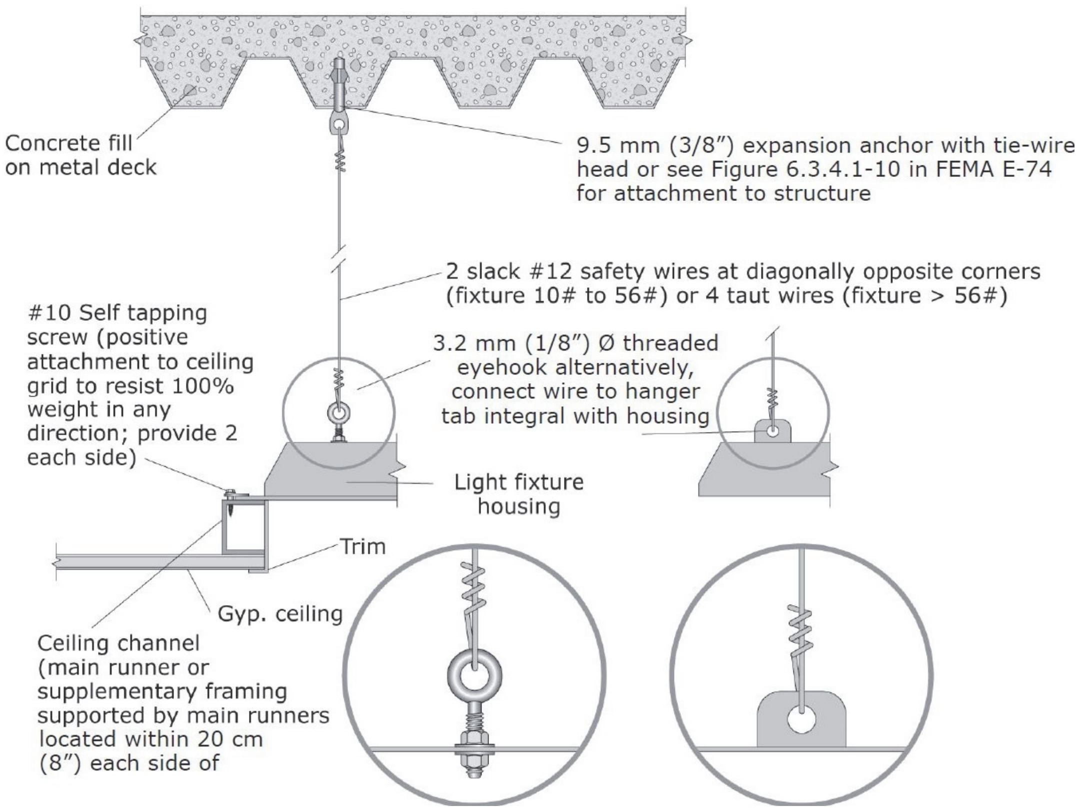


Figure 6-2 Example of recessed light fixture, 4.5 kg to 25 kg, in suspended ceiling (adapted from FEMA, 2012).

An example installation for full-height non-bearing steel stud walls is shown in Figure 6-3. Partitions taller than 1.8 meters in height should be laterally braced to the structure independent of any ceiling lateral bracing. In general, proper detailing at the head of the partition plays a critical role in reducing the severity of earthquake damage. More details on nonstructural interior partition attachments can be found in Section 6.3.2 of FEMA E-74 (FEMA, 2012).

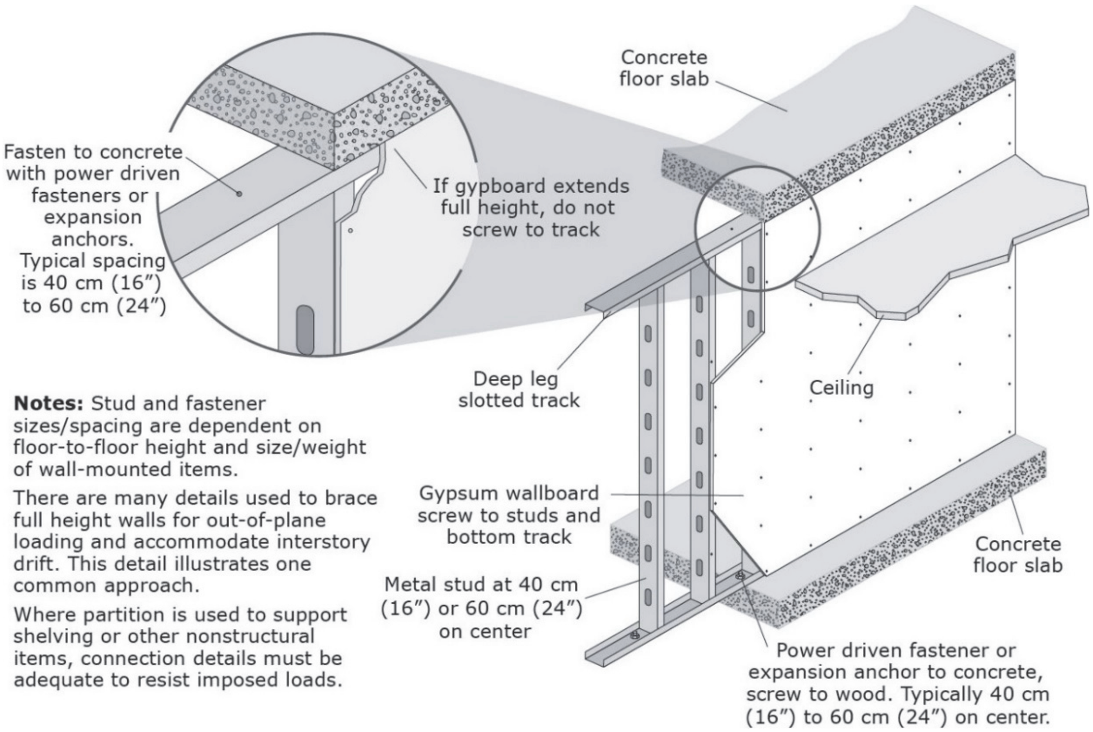


Figure 6-3 Example details for seismic attachment of non-bearing interior walls to structure (adapted from FEMA, 2012).

6.2.3 Parapets

Unreinforced stone or masonry parapets are prohibited in new school construction. In existing schools, unreinforced stone or masonry roof parapets should be braced or reinforced to prevent separation from the building and to remove potential falling hazards. Figure 6-4 illustrates an example of parapet bracing. More details on parapet bracing can be found in Section 6.3.5 of FEMA E-74 (FEMA, 2012).

6.2.4 Veneers

Bonded veneers are prohibited in new school construction because they have a history of poor performance in past earthquakes and they pose a serious falling hazard. For existing schools, it is recommended to remove heavy bonded veneers.

Figure 6-4 Example of parapet bracing (FEMA, 2012).

6.3 Mechanical, Electrical, and Plumbing Components

Mechanical, electrical, and plumbing components that may be applicable to school construction in Armenia are covered in the following sections.

It is important to connect distribution systems (piping, conduits, or ductwork) to equipment in a manner that will allow relative movement without damage. This can be accomplished through the use of flexible connections between distribution systems and the equipment.

6.3.1 Heating, Ventilating, and Air-conditioning (HVAC) Units

These units are typically suspended or roof-mounted. Adequate bracing should be provided to prevent sliding or overturning. Figure 6-5 illustrates an example detail for anchorage of roof-mounted HVAC units. More details on bracing of HVAC systems can be found in Section 6.4.1 of FEMA E-74 (FEMA, 2012).

6.3.2 Elevators

Elevators in low-rise construction of more than one story in height are typically hydraulic. Elevator guiderails must be designed for lateral restraint to resist earthquake loads and accommodate lateral story drift. All components of the hydraulic system, such as cab guides and cylinder supports, must also be restrained, anchored, or detailed to accommodate lateral drift. Corresponding mechanical and electrical equipment, sensors, piping, tanks, valves, and guides need to be properly anchored or restrained. New school drawings should call for the elevator manufacturer or supplier to provide seismic protection for the elevators. Figure 6-6 provides an example of such bracing. For more information, see Section 6.4.10 in FEMA E-74 (FEMA, 2012).

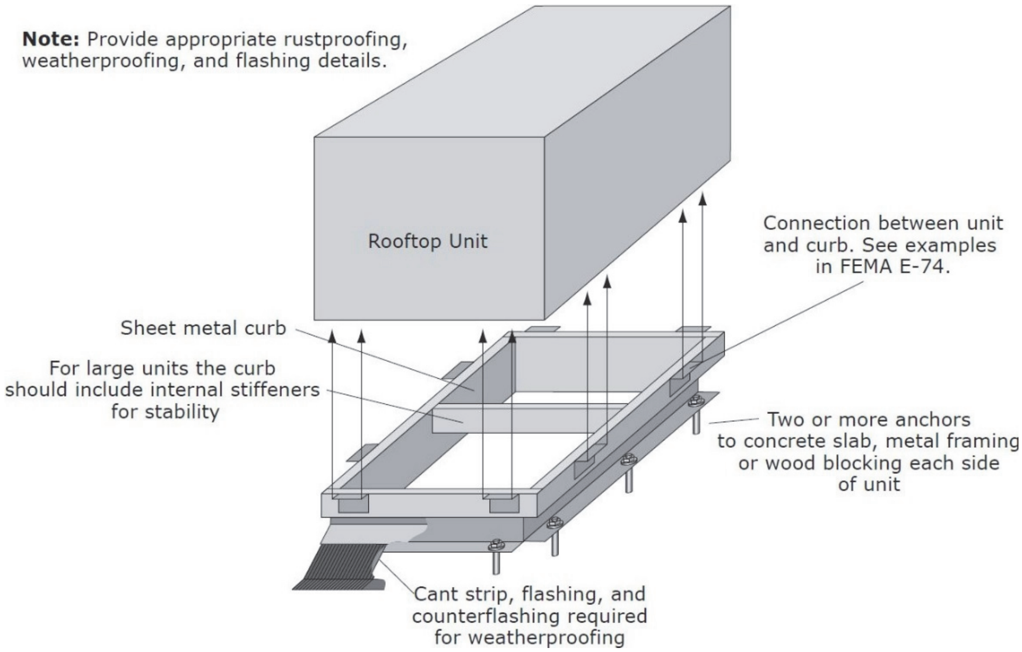


Figure 6-5 Example detail for roof-mounted HVAC unit (FEMA, 2012).

6.3.3 Water Heaters

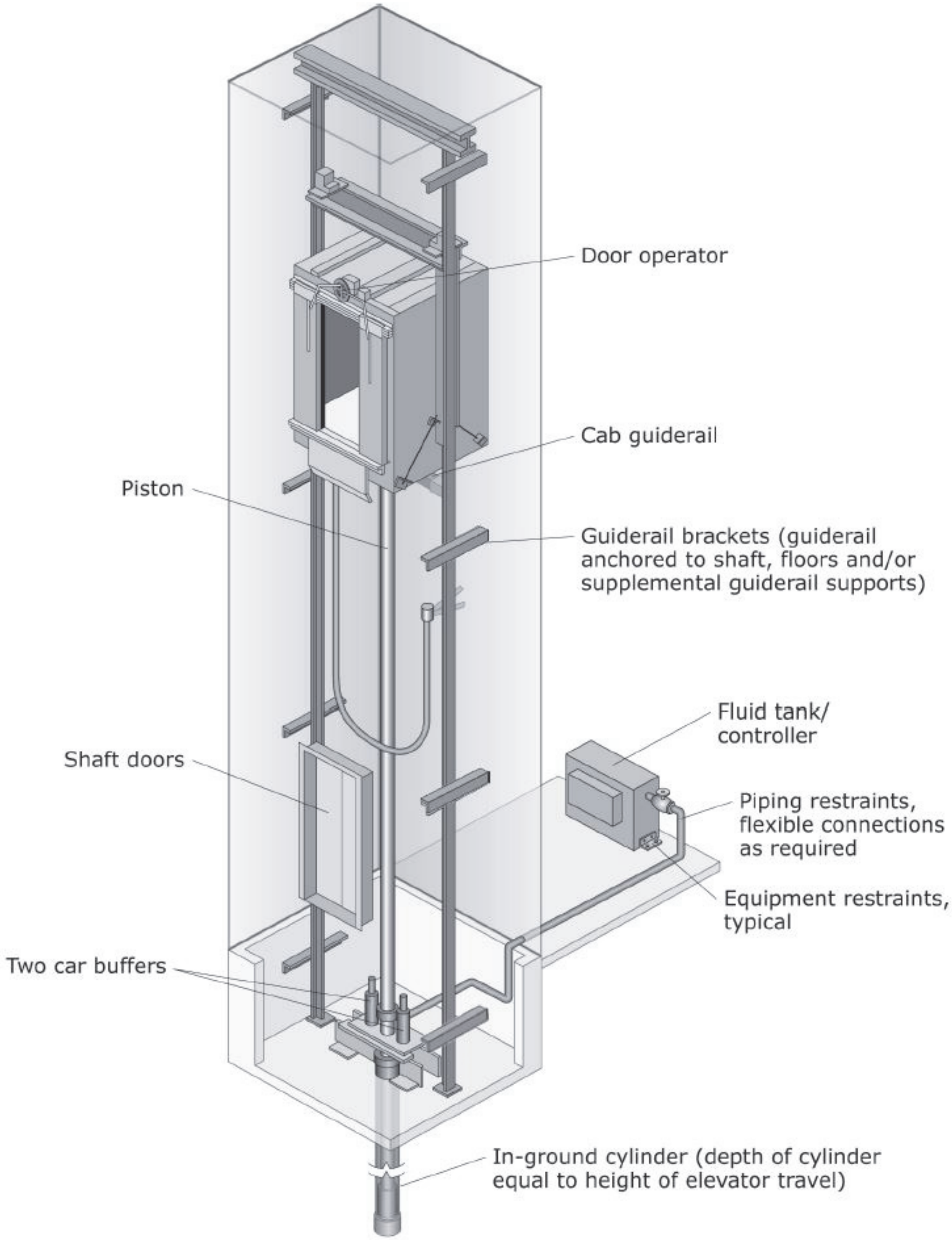
Floor mounted water heaters must be strapped to adjacent walls to prevent sliding or overturning in an earthquake. In addition to preventing sliding or overturning, bracing should be adequate to prevent damage to connecting gas and water lines, which can lead to fire or water damage following an earthquake. Figure 6-7 provides an example of lateral bracing for a water heater. For more information, see Section 6.4.2 in FEMA E-74 (FEMA, 2012).

6.3.4 Natural Gas or Propane Tanks

Natural gas or propane tanks should be adequately anchored to prevent sliding and overturning, especially in schools that will serve as emergency shelters. Anchorage and bracing for tank legs, or other supporting structure, should be provided, and connections to fuel lines and piping should be flexible to prevent damage. In addition to adequate bracing and anchorage, it is important to have automatic shutoffs to control potential gas leaks in the event of an earthquake. Figure 6-8 illustrates an example for seismic anchorage of a vertical tank. More details on anchorage of tanks can be found in Section 6.4.2 of FEMA E-74 (FEMA, 2012).

6.3.5 Emergency Power Generators

Emergency power generators should be properly anchored to prevent sliding, tilting, or overturning. Anchorage should be adequately provided for all component parts of the emergency power generation system, and flexible connections should be provided for the fuel line, exhaust ducting, and any other connected utilities. Figure 6-9 illustrates an example detail for anchorage of floor-mounted equipment, such as an emergency power generator. For more details on anchorage of emergency power generators, see Section 6.4.7.2 in FEMA E-74.



Notes: Provide lateral restraints for guiderails to resist design forces and accommodate anticipated interstory drift.
Elevators should be installed, maintained, inspected and repaired by qualified elevator technicians.
Inappropriate seismic restraints may compromise the safe operation of these systems.

Figure 6-6 Bracing and anchorage details for hydraulic elevator guiderails (FEMA, 2012).

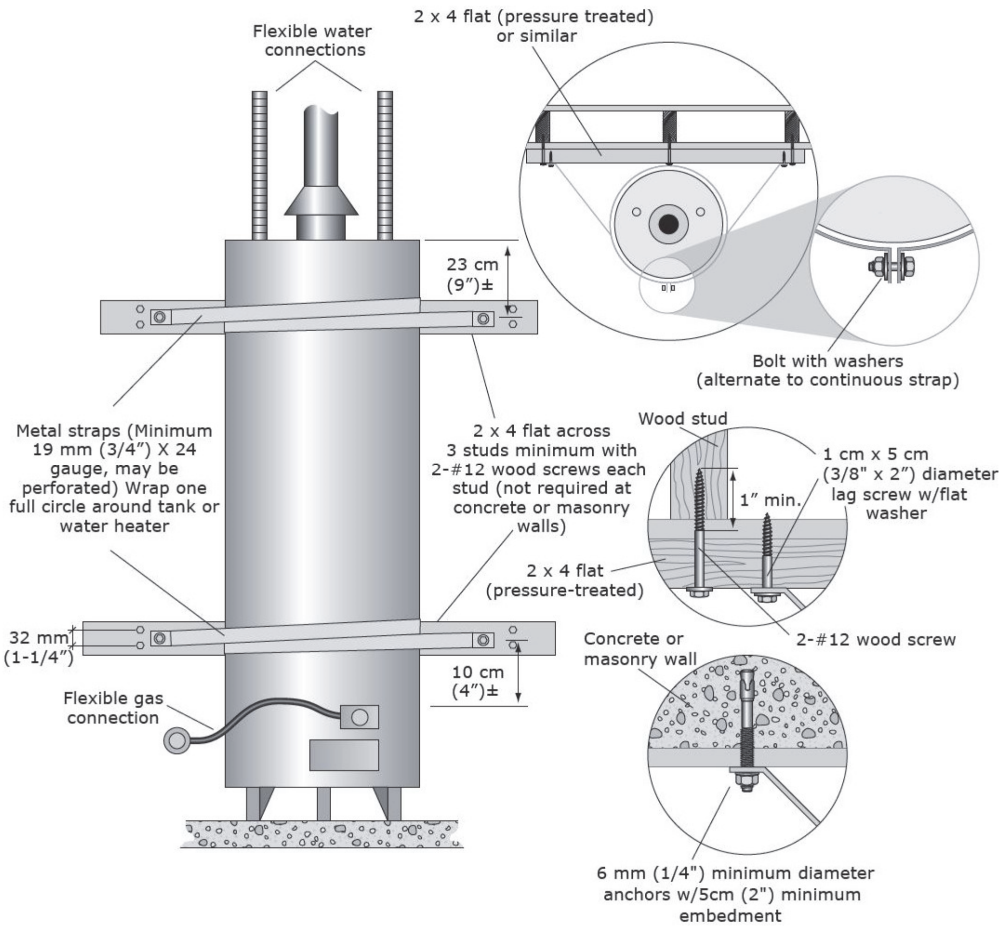


Figure 6-7 Suggested strapping details for bracing of a water heater (adapted from FEMA, 2012).

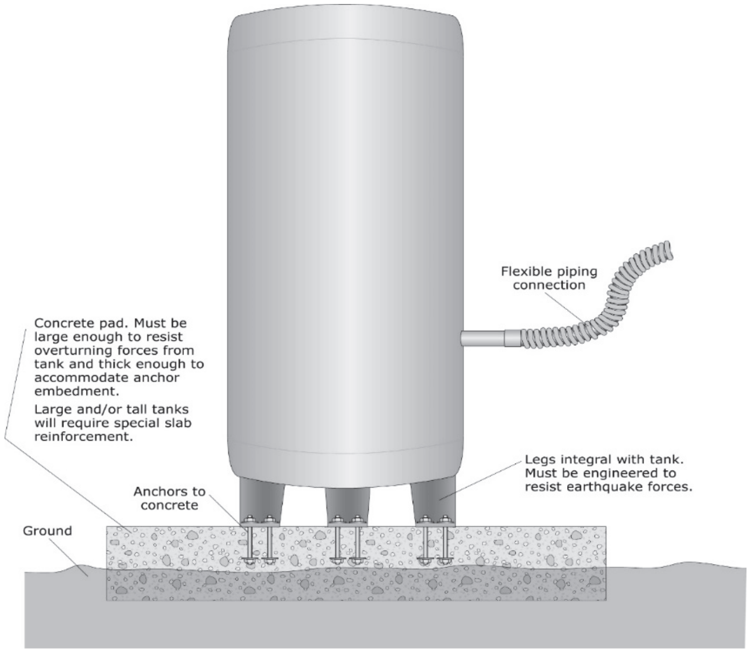


Figure 6-8 Example of anchorage for a vertical tank (FEMA, 2012).

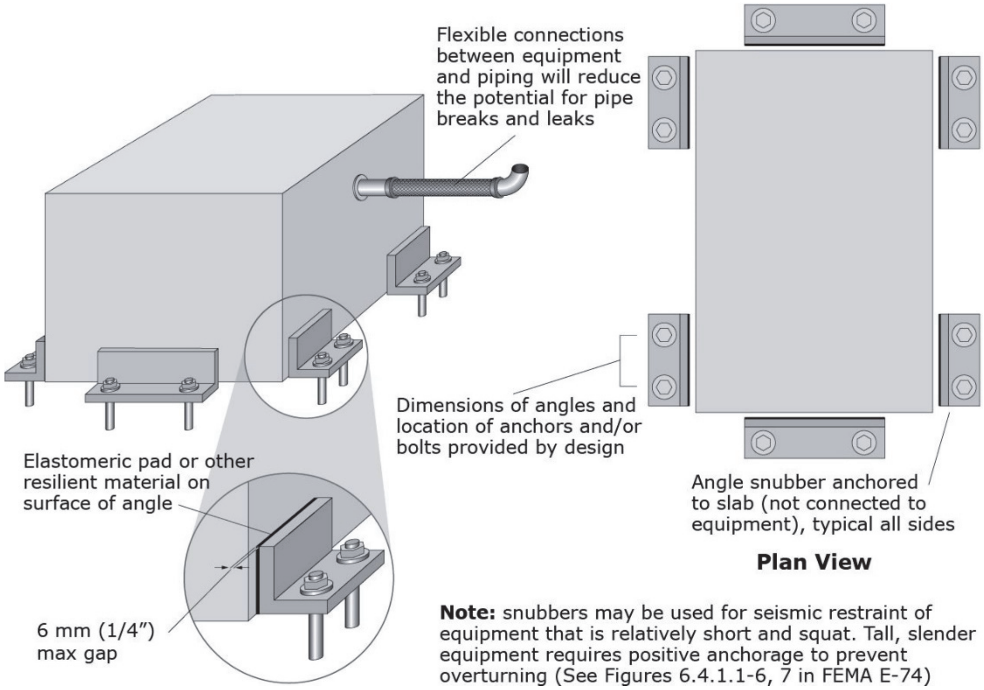


Figure 6-9 Example of anchorage for floor-mounted equipment restrained with snubbers (adapted from FEMA, 2012).

6.4 Furniture, Fixtures, and Equipment

Furniture, fixtures, and equipment that may be applicable to school construction in Armenia are covered in the following sections.

6.4.1 Wall-Mounted Equipment

Wall-mounted equipment, including televisions, video monitors, and other teaching aids, should be properly braced and anchored. This is especially important for equipment that is over 9 kg and mounted more than 1.2 meters above the floor level. Lightweight (less than 22 kg) proprietary mounting brackets for monitors, and other wall-mounted equipment are commonly available. An example of such a bracket is illustrated in Figure 6-10. These products, if rated for seismic loading and properly installed, can provide for a safe installation. More details on wall-mounted equipment can be found in Section 6.5.3 of FEMA E-74 (FEMA, 2012).

6.4.2 Bookshelves

Bookshelves frequently overturn in an earthquake unless they are properly anchored. Bookshelves taller than 1.2 meters in height must be anchored to prevent overturning, which is a requirement in ASCE/SEI 41-06 (ASCE, 2006) when the performance objective is life safety or higher. Figure 6-11 illustrates an example for bookshelf bracing and anchorage. More details on bracing of bookshelves and shelving can be found in Section 6.5.2 of FEMA E-74 (FEMA, 2012).

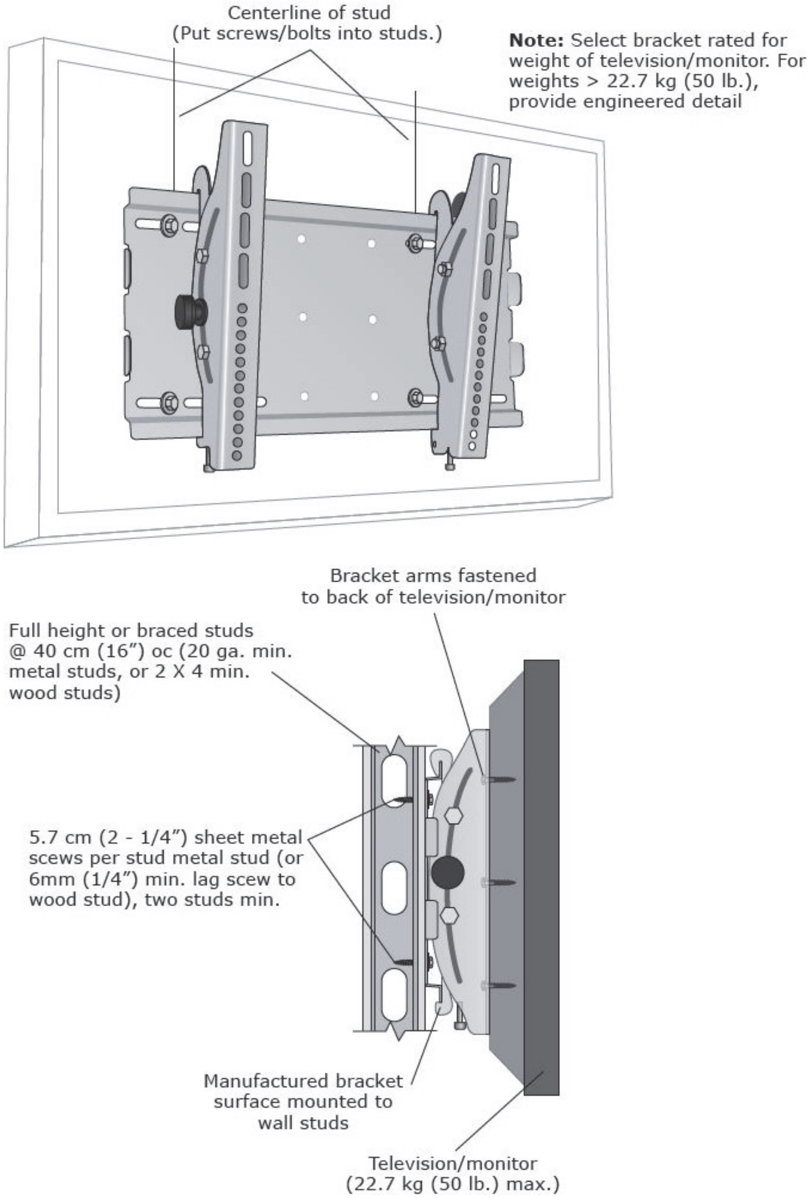


Figure 6-10 Example of earthquake mounting bracket for television monitors (adapted from FEMA, 2012).

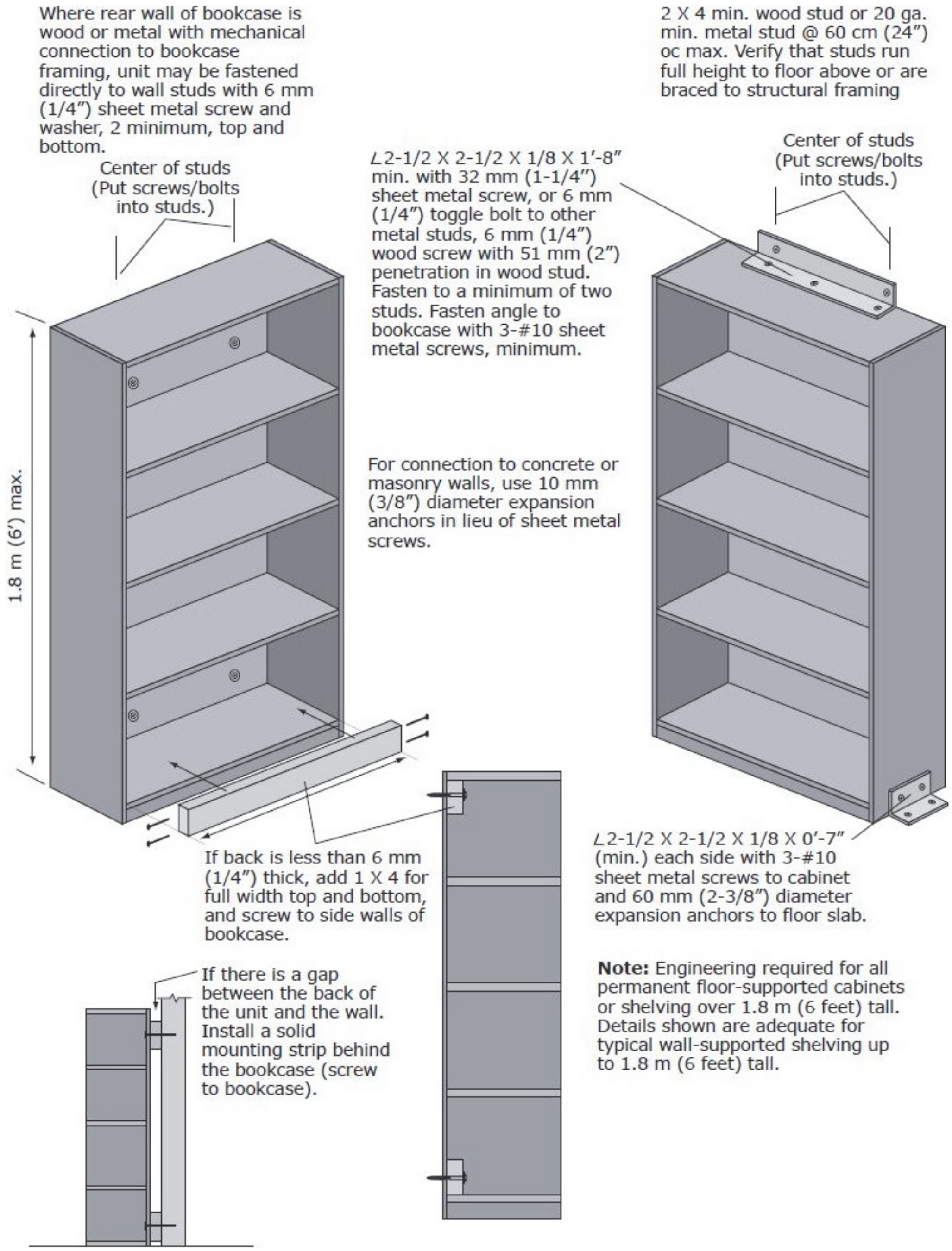


Figure 6-11 Example of bookshelf bracing and anchorage (adapted from FEMA, 2012).

Chapter 7

Implementation Recommendations

To achieve the intended seismic performance in a major earthquake, implementation of these *Guidelines* will require quality control at each step of the implementation process. This chapter outlines recommendations for design review, construction quality control and inspection, and ongoing maintenance of school facilities.

7.1 Independent Design Review

To ensure adequate seismic design of schools, all structural designs, whether for retrofit or new school construction, should be conducted by a licensed engineering organization, and should be peer reviewed for compliance with RABC II-6.02-2006, compliance with these *Guidelines*, and overall quality and constructability.

All structural designs, for retrofit or new school construction, should undergo a peer review by independent professional structural engineers, with extensive experience, including international experience, in earthquake-resistant design. Peer reviewers should be selected by the organization funding the school construction (defined herein as the owner), and should not have any existing or potential conflicts of interest with the work being reviewed.

Peer review engineers should place identifying information on the construction documents along with the date of the review to indicate concurrence with the technical information contained therein and document that the review has taken place.

Peer review should be conducted upon: (1) completion of schematic structural design drawings, and (2) 90% completion of structural design drawings, prior to commencement of bidding for construction.

Design engineers and peer review engineers should be trained on the content and recommendations contained in these *Guidelines* to help ensure that they are understood and followed correctly.

7.2 Construction Quality Control and Inspection

To ensure that school construction is in conformance with the structural design, and is of sufficient quality, construction quality control and inspection is necessary.

Design engineers should note on the drawings and in the construction documents the components of the design that require inspection for construction quality control, and whether inspection should occur continuously or at certain stages of construction.

The organization funding the school construction (defined herein as the owner; not the construction contractor or subcontractors) should employ inspectors that are experienced in the areas of construction being inspected, and have no existing or potential conflicts of interest in the work being inspected. Inspectors should be paid by the owner, and should report the results of their inspections, including whether or not the construction meets the project requirements, to the owner and the engineer. Inspectors should operate independently from the contractor.

The owner should assign construction roles and responsibilities, and establish and maintain appropriate reporting procedures, to promote construction quality:

- The contractor, engineers, and project manager should be hired by the owner.
- On-site inspectors should be hired by the owner and operate independently from the contractor.
- Appropriate materials testing laboratories should be hired to monitor and verify the quality of materials used in construction, such as concrete quality. Testing laboratories should not have a conflict of interest with the contractor.
- Inspectors must observe and certify satisfactory conditions at all stages of construction, before project close-out and final certification. Any observed deficiencies must be corrected prior to certification.
- During the construction process, inspectors and engineers should be on-site to ensure that the construction is in conformance with the approved structural design and Armenian building code requirements.
- The contractor, engineers, and project manager must all ensure that the project documentation is complete, and that all required approvals have been obtained. This is to ensure that a clear chain of certifications and responsibilities exists, and to demonstrate that the work was completed in accordance with the approved plans and Armenian building code requirements. Liability for safe, code-compliant design and construction, however, remains with the design engineer and the contractor, not the inspectors.
- To ensure work is carried out on schedule, construction contracts should guarantee project delivery by an agreed upon date.

7.3 Maintenance

Lack of maintenance is a significant and ongoing problem in existing Armenian schools. Effective and ongoing maintenance of school buildings is essential for structural and earthquake safety, as well as for proper educational function.

Attention for ongoing, long-term maintenance programs should include, but is not limited to, the following items:

- Anti-seismic joints between buildings are frequently filled with debris, or “repaired” with rigid materials that prevent the joints from functioning to isolate the response of independent buildings during an earthquake. Anti-seismic joints should always be maintained, and, when necessary, repaired with proper compressible materials to ensure functionality.

- Leaking roofing membranes and damaged glazing can lead to significant water intrusion, corrosion, spalling, and deterioration in the structure over time. The condition of the exterior building envelope should be regularly weather-proofed and maintained.
- Poor drainage and accumulation of water around buildings can cause structural deterioration and foundation settlement. Roof and site drainage should not be allowed to accumulate around buildings and should be directed offsite.
- Exterior concrete and masonry cracks are common in school buildings and should be regularly patched and sealed to prevent water intrusion that can lead to corrosion and deterioration in the structure over time.
- Replacement of mechanical, electrical, or plumbing equipment, interior reconfiguration of space, remodeling, or modernization of school buildings should follow the recommendations and intent of these *Guidelines*. For example, reconfigured partition walls should be constructed of modern, lightweight materials, and new equipment should be braced and anchored for seismic forces in accordance with Chapter 6.

Appendix A

School Data Collection and Evaluation Form

This Appendix provides a recommended form for data collection and evaluation of school buildings that are being considered for retrofit. The purpose of the data collection and evaluation form is to: (1) ensure that a site visit to observe existing conditions is conducted; (2) collect relevant data in an organized and consistent manner; (3) gather information to help determine if the school building is a good candidate for retrofit; (4) describe and assess the condition of the site and buildings; and (5) identify seismic deficiencies that must be corrected as part of the retrofit.

This form is intended to be reproduced as many times as necessary. One form should be completed for each building, and should be accompanied by photographs documenting all important observations including exterior elevations, seismic deficiencies, structural deterioration, site conditions, and other functional or operational concerns at the site.

SCHOOL DATA COLLECTION AND EVALUATION FORM

SCHOOL BUILDING AND SITE DESCRIPTION

Name of Reviewer(s): ______________________________

School ID: __________________________ **Date:** _________

Location: ____

No. Buildings on Site: _______ **Plans Available:** ☐ Yes ☐ No

Student Capacity: _________ **Current Enrollment:** __________

Building ID: ___________________ **No. Stories:** __________

Dimensions: __________________ **Story Height:** _________

Year Built: _______ **Year rehabilitated/remodeled:** __________

Description of rehabilitation/remodeling: ________________

____

____

____

Description of Building and Site:
(Attach sketch with the number and configuration of buildings. Label buildings to coordinate with forms.)

____

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____

Structural Typology*:*

☐ **A:** exterior and interior masonry bearing walls

☐ **B:** exterior masonry bearing walls; interior precast or monolithic concrete frames

☐ **C:** exterior precast concrete frame; interior precast bearing walls

☐ **D-1:** distributed precast concrete frame (up to 2 stories)

☐ **D-2:** distributed precast concrete frame (3-4 stories)

☐ Not defined

☐ Other: ______________________________________

Floor and Roof Construction: ☐ Precast concrete ☐ Wood ☐ Steel

Basement: ☐ Yes ☐ No ☐ Not accessible

Site and Topography: ☐ Flat ☐ Minor sloping site ☐ Major sloping site

Site Hazards: ☐ Landslide zone ☐ Flood zone ☐ Liquefaction zone ☐ Within 10 km of a mapped fault

Past Earthquake Studies Performed:
(List by organization and date.)

____

____

SEISMIC DEFICIENCIES

(Check all that apply and include photos to document.)

Roof:
- ☐ Precast concrete planks without topping slab
- ☐ Wood or steel construction with inadequate diaphragm

Floors:
- ☐ Precast concrete planks without topping slab
- ☐ Wood construction with inadequate diaphragm

Exterior Walls:
- ☐ Bearing walls of unreinforced masonry or stone construction
- ☐ Non-bearing walls of unreinforced masonry or stone construction
- ☐ Inadequately anchored masonry veneer
- ☐ Inadequately anchored precast wall panels

Interior Walls:
- ☐ Bearing walls of unreinforced masonry or stone construction
- ☐ Unreinforced masonry partitions

Structural Frame and Connectivity:
- ☐ Precast concrete beam-column frame construction
- ☐ Weak/non-ductile precast concrete frame connections
- ☐ Lack of positive connection between masonry walls and floor or roof diaphragms
- ☐ Lack of positive connection between precast floor/roof planks and supporting frames or walls
- ☐ Anti-seismic joints are filled with debris

Foundation:
- ☐ Rubble strip foundations under bearing walls
- ☐ Isolated pad foundations without grade beams

Seismic Anchorage of Nonstructural Components:
- ☐ Unanchored tall furnishings (bookshelves, file cabinets)
- ☐ Unbraced suspended ceilings or lights
- ☐ Unanchored mechanical equipment
- ☐ Unbraced parapets or chimneys

Other Observed Deficiencies: ____

____

BUILDING CONDITION ASSESSMENT

(Check all that apply and include photos to document.)

Structural Condition:

Evidence of corrosion of reinforcing steel or spalling of concrete at:

- ☐ Roof
- ☐ Floors
- ☐ Connections
- ☐ Other: ____

Evidence of vertical distress including significant deflection or loss of vertical-load-carrying capacity at:

- ☐ Roof
- ☐ Floors
- ☐ Connections
- ☐ Other: ____

Evidence of prior damage or distress:

- ☐ Cracking on underside of floor or roof framing
- ☐ Diagonal cracking in walls
- ☐ Cracking in beams, columns, or in vicinity of joints
- ☐ Cracking in foundations
- ☐ Other: ____

Structural Condition (continued):

Evidence of differential settlement or foundation movement:

- ☐ Yes
- ☐ No

Building Envelope and Site Condition:

- ☐ Improper or inadequate slope for drainage at site
- ☐ Evidence of significant water intrusion
- ☐ Evidence of failure in roofing
- ☐ Evidence of failure in seals around windows and doors
- ☐ Notes on general condition of envelope or site:

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Overall Building Condition:

- ☐ Good: Minor repairs necessary in addition to seismic retrofit
- ☐ Fair: Significant repairs necessary in addition to seismic retrofit
- ☐ Poor: Major repairs necessary in addition to seismic retrofit
- ☐ Notes on general condition of building:

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Other Functional or Operational Considerations:

- ☐ Roof and site rain water is properly controlled and directed away from the building (and off site)
- ☐ The roofing envelope has been maintained in good condition to prevent water intrusion
- ☐ Exterior windows and glazing have been updated for energy efficiency and maintained to prevent water intrusion
- ☐ Mechanical and electrical systems have been updated for energy efficiency and maintained in good condition
- ☐ Interior finishes have been updated or modernized
- ☐ Past evidence of structural damage has been repaired and maintained in good condition
- ☐ Anti-Seismic joints are clear and gaps are functioning as intended

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GENERAL COMMENTS

(Consider building age, condition, deficiencies, possible historic significance, demographics, and other functional or operational considerations to provide an overall opinion on the feasibility for retrofit and recommended prioritization.)

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Instructions for use:

- A separate form should be completed for each building at the site (defined by location of anti-seismic joints).
- Important observations, including exterior elevations, seismic deficiencies, structural deterioration, site conditions, and other functional or operational concerns should be documented with photographs.
- Standard plans for each school typology are readily available and should be used to facilitate data collection and evaluation.
- Existing geotechnical information, if available, should be collected and reviewed to understand the underlying soil conditions.
- Investigation of existing foundations (when plans are not available) is difficult and costly. When necessary, foundations can be investigated through observation pits excavated at specific locations. When foundation conditions are not known, assumptions made during design must be confirmed, and modified as necessary, based on field observations during construction.

Appendix B

Conceptual Seismic Retrofit for Typology A Buildings

This Appendix provides a structural narrative, plans, and typical details for conceptual seismic retrofit of Typology A typical classroom and gymnasium buildings. Conceptual seismic retrofit plans and details provided in this appendix are summarized in Table B-1.

Table B-1 Conceptual Seismic Retrofit Drawings for Typology A Buildings

Figure Number	*Figure Title*	*Page Number(s)*
B-1	Typology A typical classroom - foundation plan	B-4
B-2	Typology A typical classroom - ground floor plan	B-5
B-3	Typology A typical classroom - second floor plan	B-6
B-4	Typology A typical classroom - roof plan	B-7
B-5	Typology A typical classroom - transverse section	B-8
B-6	Typology A typical classroom - transverse section and details	B-9
B-7	Typology A typical classroom - transverse section and details	B-10
B-8	Typology A typical classroom - longitudinal section and details	B-11
B-9	Typology A typical classroom - typical details	B-12
B-10	Typology A typical classroom - typical details	B-13
B-11	Typology A typical gymnasium - foundation plan	B-14
B-12	Typology A typical gymnasium - ground floor plan	B-15
B-13	Typology A typical gymnasium - roof plan	B-16
B-14	Typology A typical gymnasium - transverse section and details	B-17
B-15	Typology A typical gymnasium - transverse section	B-18
B-16	Typology A typical gymnasium - longitudinal section and details	B-19
B-17	Typology A typical gymnasium - typical details	B-20
B-18	Typology A typical gymnasium - typical details	B-21

B.1 Structural Narrative – Typology A Typical Classroom Building

The steps for construction of conceptual seismic retrofit of Typology A typical classroom buildings are as follows:

- Identify and demolish all interior masonry partitions that are non-load bearing, and will not be used as a back-form for new reinforced concrete shear walls.
- Prepare existing surfaces of precast concrete plank floor and roof systems by removal of nonstructural concrete, grout, roofing, and other finish materials. Prepare surfaces to receive new topping slab by chipping and sand-blasting to a clean and rough condition.
- Prepare surfaces of existing masonry walls to receive new reinforced concrete by removing plaster or other nonstructural finishes, and removing loose cement mortar between blocks to a depth of 2-3 cm.
- Provide sufficient dowels through existing masonry walls (60 cm maximum spacing each way, staggered for spacing of anchors) to transfer all seismic loads to the new reinforced concrete shear walls.
- Supplement and reinforce existing rubble foundations with new reinforced concrete foundation elements. The elevation of interior slabs-on-grade vary from building to building. The elevation of the top of footing should be verified in the field.
- Place new reinforced concrete shear walls on the interior face of all exterior bearing walls (including the basement) with concrete of sufficient strength (minimum of 20 MPa; cylindrical strength), thickness (minimum of 15 cm for two stories and single-sided), and reinforcement (20 cm maximum spacing each way for reinforcing bars) to resist specified gravity loads and in-place and out-of-plane seismic loads, as well as any torsional effects. All reinforcing steel must be adequately chaired within forms and held in position during placement of concrete.
- Place new reinforced concrete shear walls on both faces of interior bearing walls (including the basement) with concrete of sufficient strength (minimum of 20 MPa; cylindrical strength), thickness (minimum of 15 cm for two stories and single-sided), and reinforcement (20 cm maximum spacing each way for reinforcing bars) to resist specified gravity loads and in-plane and out-of-plane seismic loads. All reinforcing steel must be adequately chaired within forms and held in position during placement of concrete. New concrete shear walls are shown on the surface of existing masonry walls. Extending new reinforced concrete around window and door openings and edges of walls could be considered on a case-by-case basis, but is not considered necessary for the conceptual retrofit scheme shown.
- Construct a cast-in-place reinforced concrete topping slab using concrete of sufficient thickness (65 mm minimum thickness), and reinforcement (20 cm maximum spacing each way for reinforcing bars) on the surface of all precast floor and roof planks. Lightweight concrete may be used for topping slabs to reduce the added weight. Provide epoxy dowels between the new topping slab and the precast planks. Provide reinforcing dowels between the new shear walls and the new topping slabs to transfer in-plane and out-of-plane seismic loads between the walls and the diaphragms.

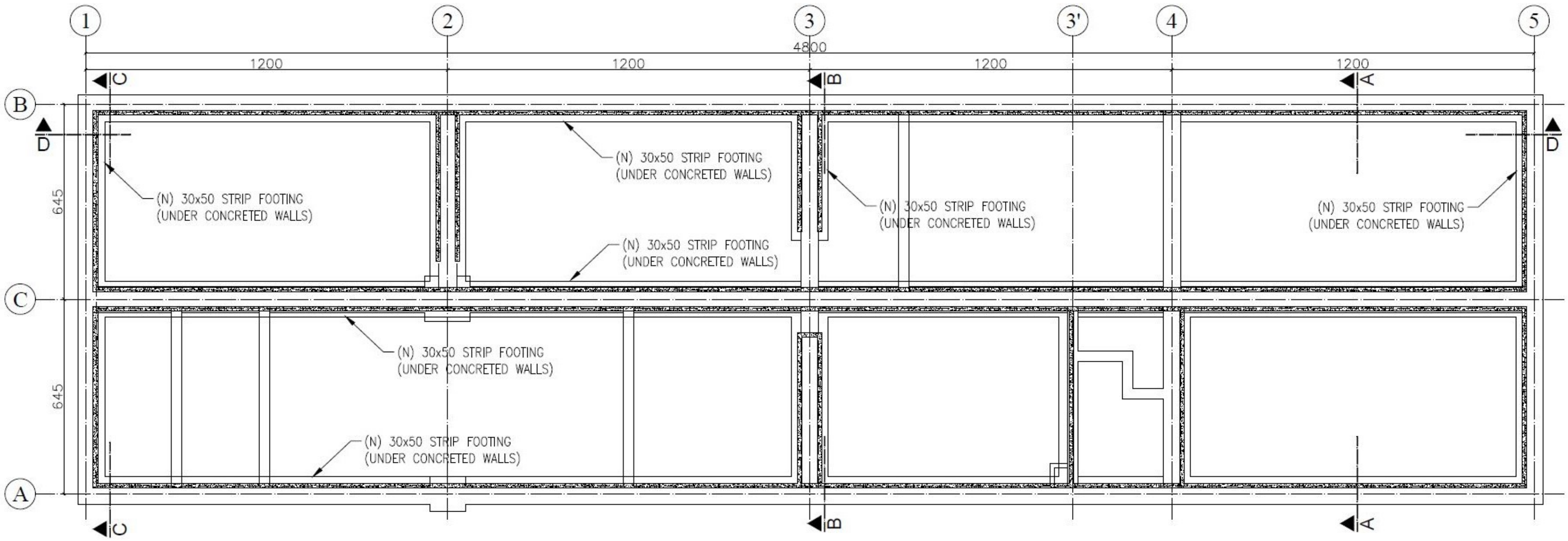
- Replace roofing and floor finishes with new lightweight materials over the reinforced concrete topping slab.
- Replace demolished masonry partitions with modern lightweight cold-formed steel studs and gypsum wallboard. Construct new lightweight interior partitioning between classrooms and corridors, as needed.
- Clear, widen (as necessary), and protect (with appropriate architectural details) all anti-seismic joints between building wings.

B.2 Structural Narrative – Typology A Typical Gymnasium Building

The steps for construction of conceptual seismic retrofit of Typology A typical gymnasium buildings are as follows:

- Prepare existing surfaces of precast concrete roof systems by removal of roofing, insulation, and other finish materials. Prepare surfaces to receive new topping slab by chipping and sand-blasting to a clean and rough condition.
- Prepare surfaces of existing masonry walls to receive new reinforced concrete by removing plaster or other nonstructural finishes, and removing loose cement mortar between blocks to a depth of 2-3 cm.
- Provide sufficient dowels through existing masonry walls (60 cm maximum spacing each way, staggered for spacing of anchors) to transfer all seismic loads to the new reinforced concrete shear walls.
- Supplement and reinforce existing rubble foundations with new reinforced concrete foundation elements.
- Place new reinforced concrete shear walls on both faces of exterior bearing walls (including the basement) with concrete of sufficient strength (minimum of 20 MPa; cylindrical strength), thickness (minimum of 15 cm for two stories), and reinforcement (20 cm maximum spacing each way for reinforcing bars) to resist specified gravity loads and in-place and out-of-plane seismic loads. All reinforcing steel must be adequately chaired within forms and held in position during placement of concrete.
- Construct a cast-in-place reinforced concrete topping slab using concrete of sufficient thickness (100 mm minimum thickness), and reinforcement (20 cm maximum spacing each way for reinforcing bars) on the surface of precast roof system. Lightweight concrete may be used for topping slabs to reduce the added weight. Provide epoxy dowels between the new topping slab and the precast planks. Provide reinforcing dowels between the new shear walls and the new topping slabs to transfer in-plane and out-of-plane seismic loads between the walls and the diaphragms.
- Replace roofing and insulation with new lightweight materials, sloped to drain, over the reinforced concrete topping slab.
- Clear, widen (as necessary), and protect (with appropriate architectural details) anti-seismic joints at adjacent buildings.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALL BOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.
4. FOR COLLECTOR REINFORCEMENT SEE TYPICAL DETAIL J AND K.



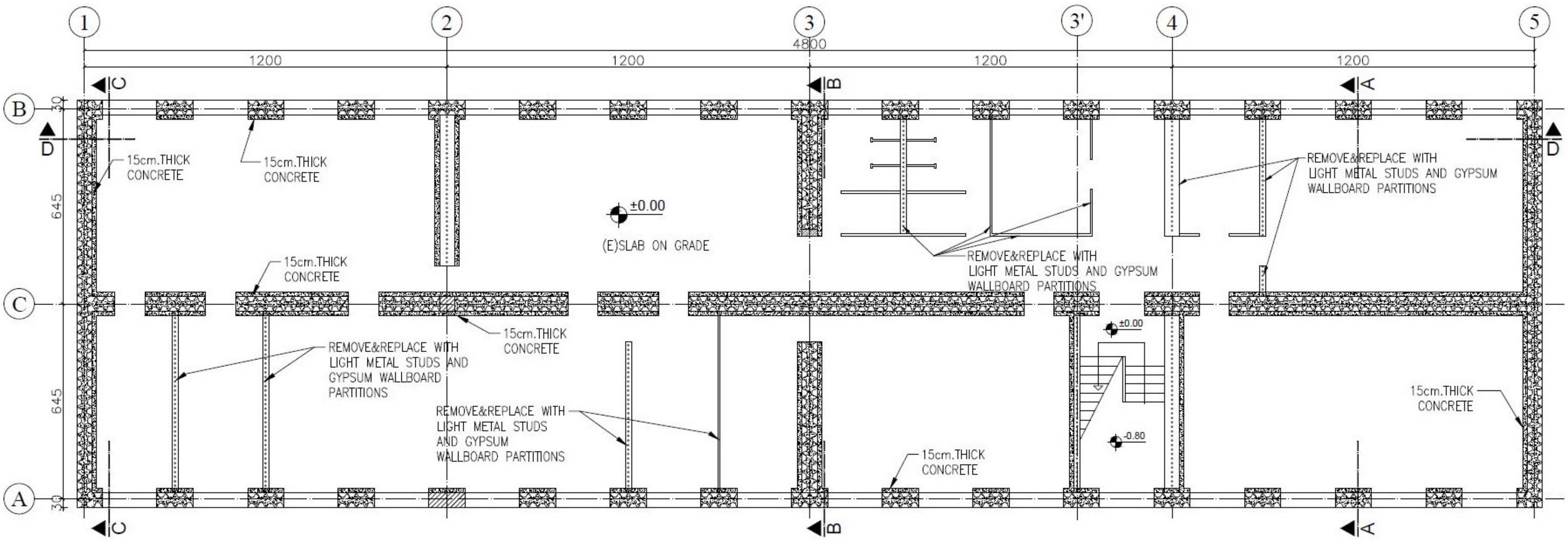
FOUNDATION PLAN
(BOTTOM OF FOUNDATION -1.70)

Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

Figure B-1 Typology A typical classroom - foundation plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALL BOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.
4. FOR COLLECTOR REINFORCEMENT SEE TYPICAL DETAIL J AND K.



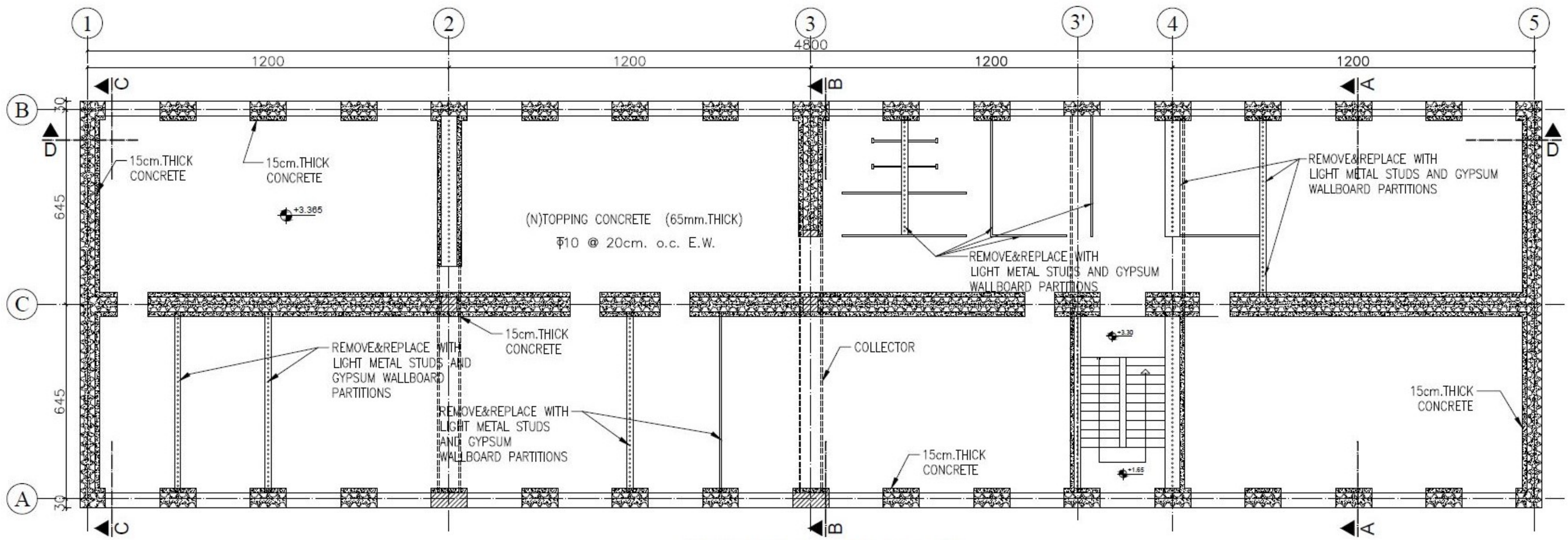
GROUND FLOOR PLAN (±0.00)

Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

Figure B-2 Typology A typical classroom - ground floor plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALL BOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.
4. FOR COLLECTOR REINFORCEMENT SEE TYPICAL DETAIL J AND K.



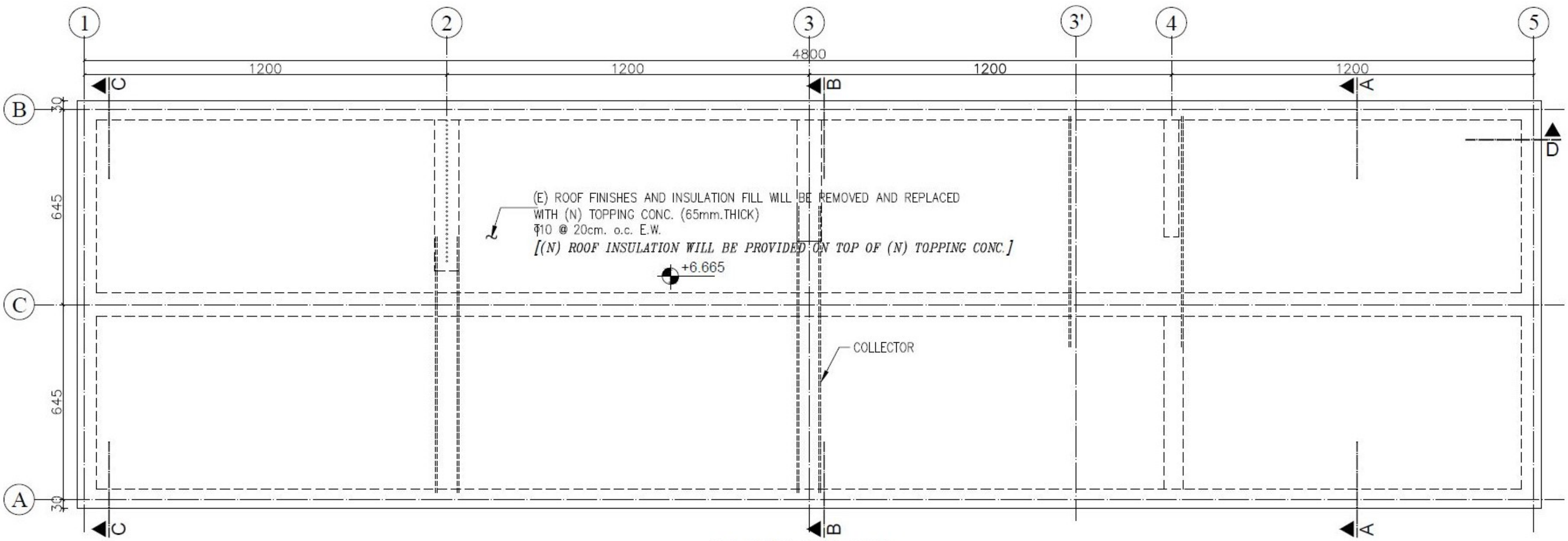
SECOND FLOOR PLAN (+3.30)

Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (fy)	A500C
(E) PEMZA		
(E) TUFA		

Figure B-3 Typology A typical classroom - second floor plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALL BOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.
4. FOR COLLECTOR REINFORCEMENT SEE TYPICAL DETAIL J AND K.

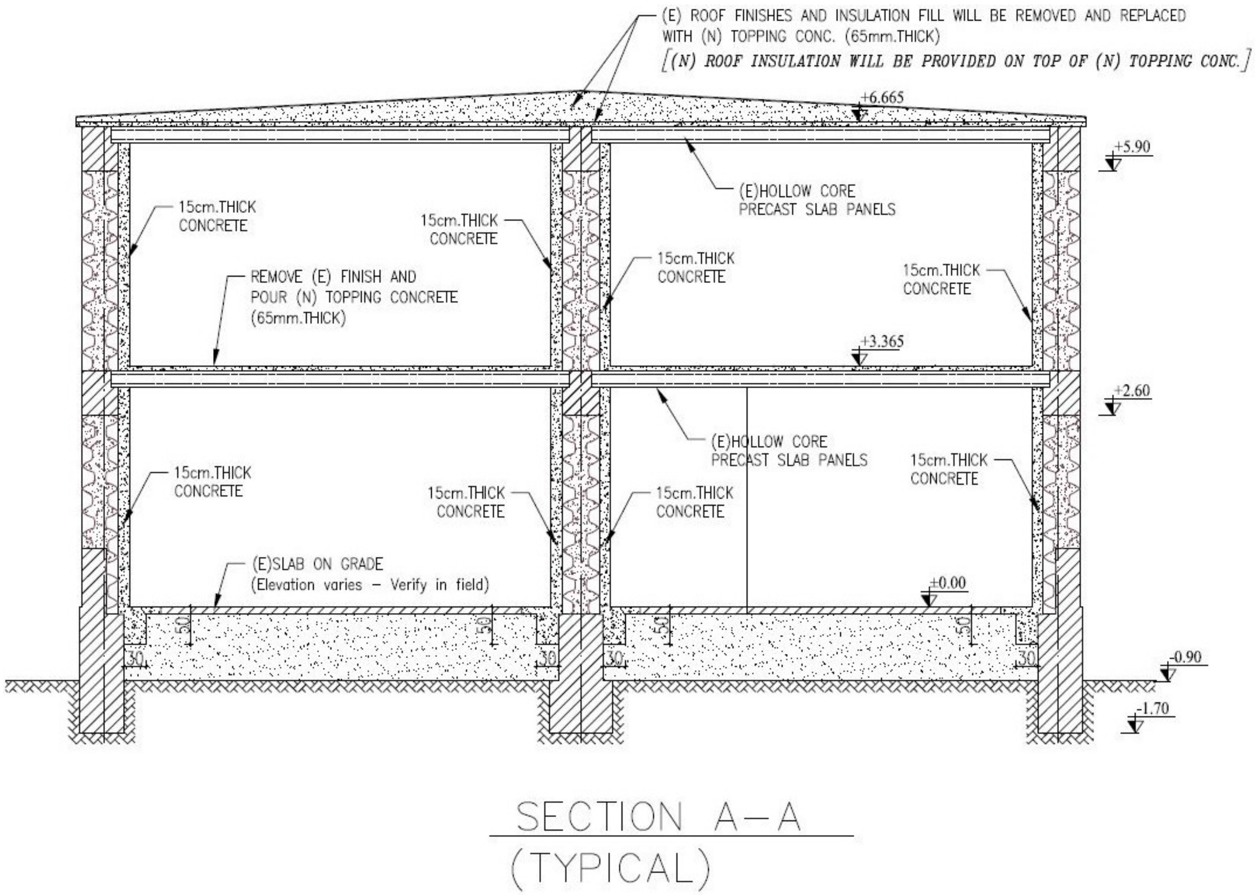


ROOF PLAN (+6.60)

Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

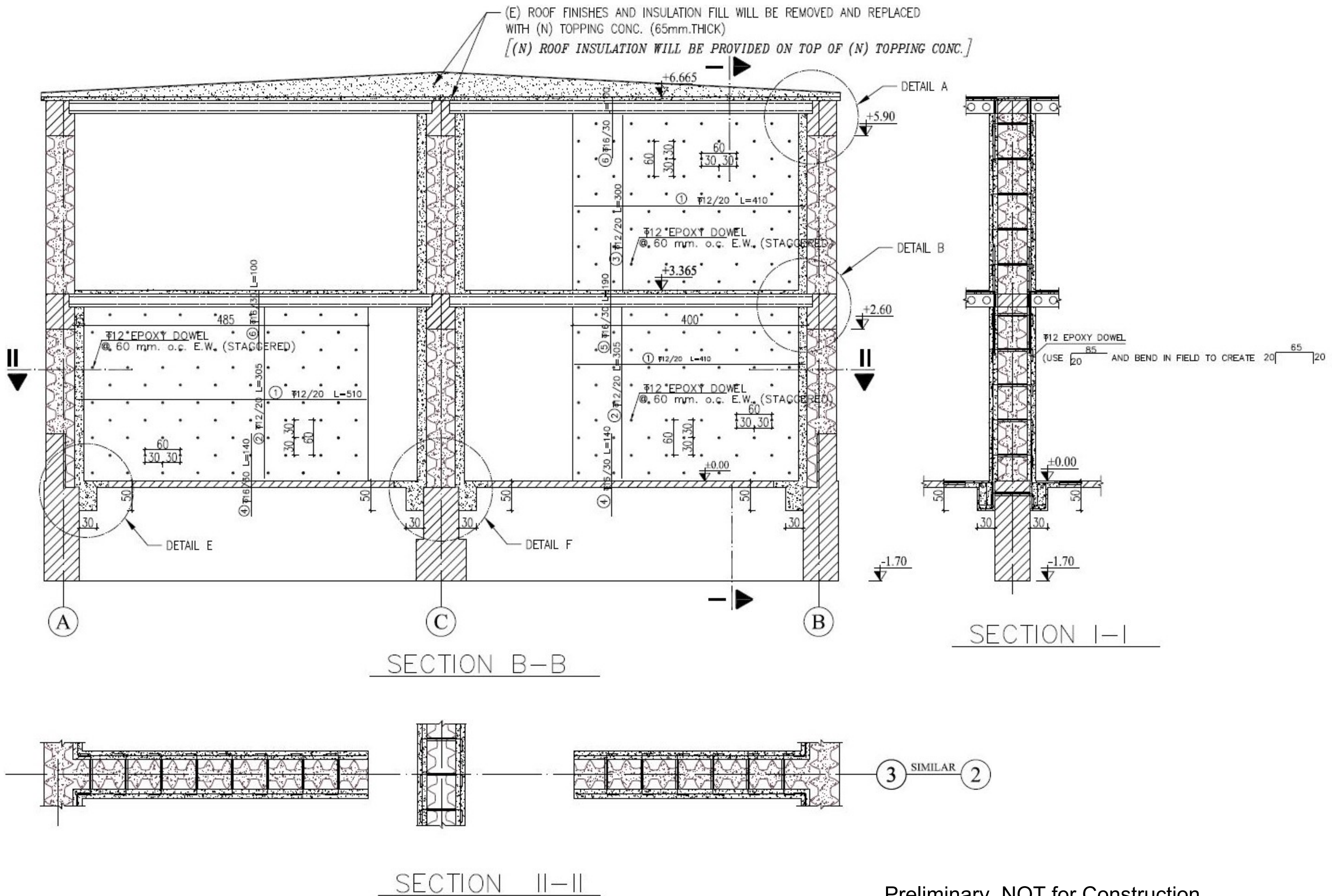
Figure B-4 Typology A typical classroom - roof plan.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

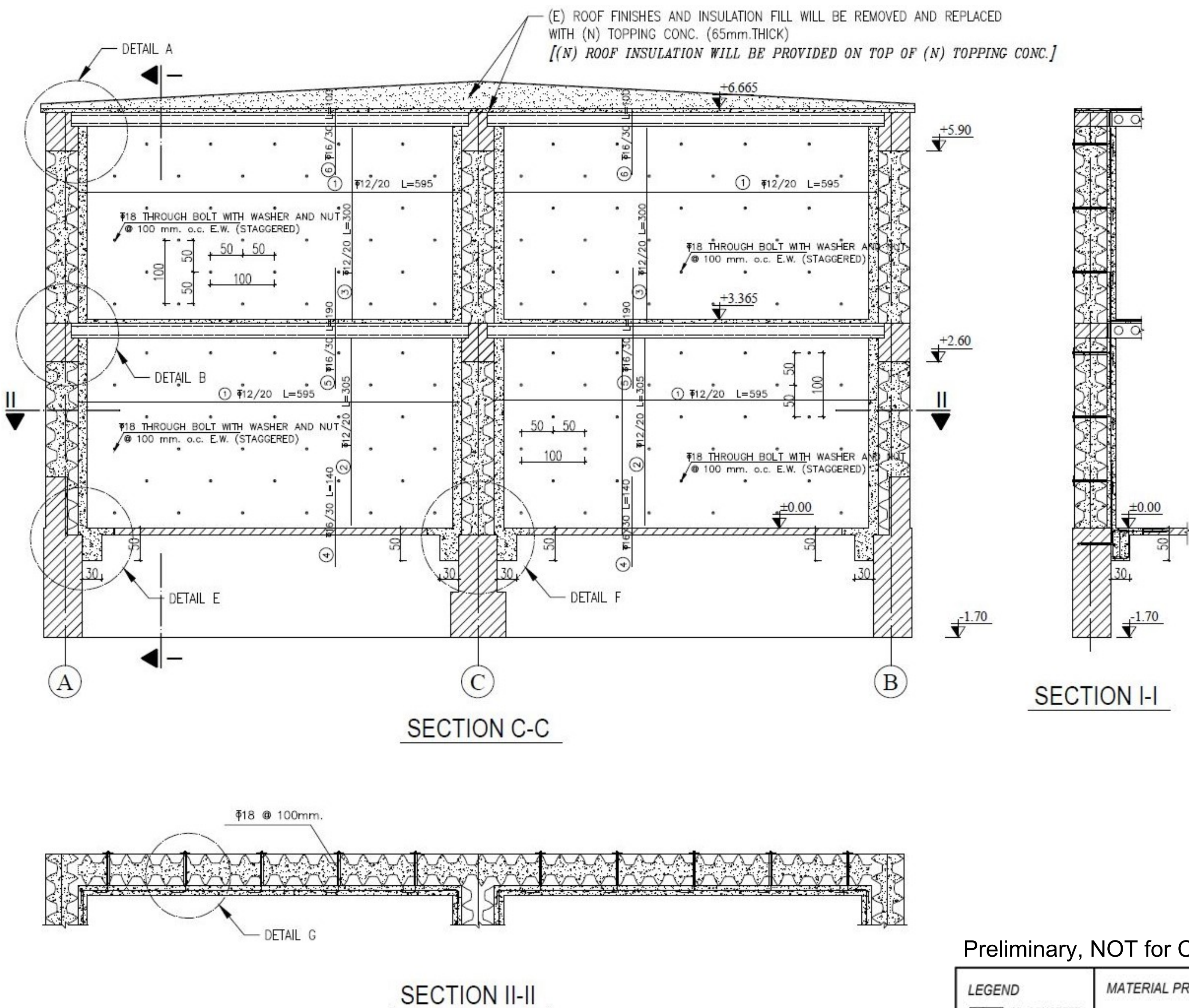
Figure B-5 Typology A typical classroom - transverse section.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

Figure B-6 Typology A typical classroom - transverse section and details.

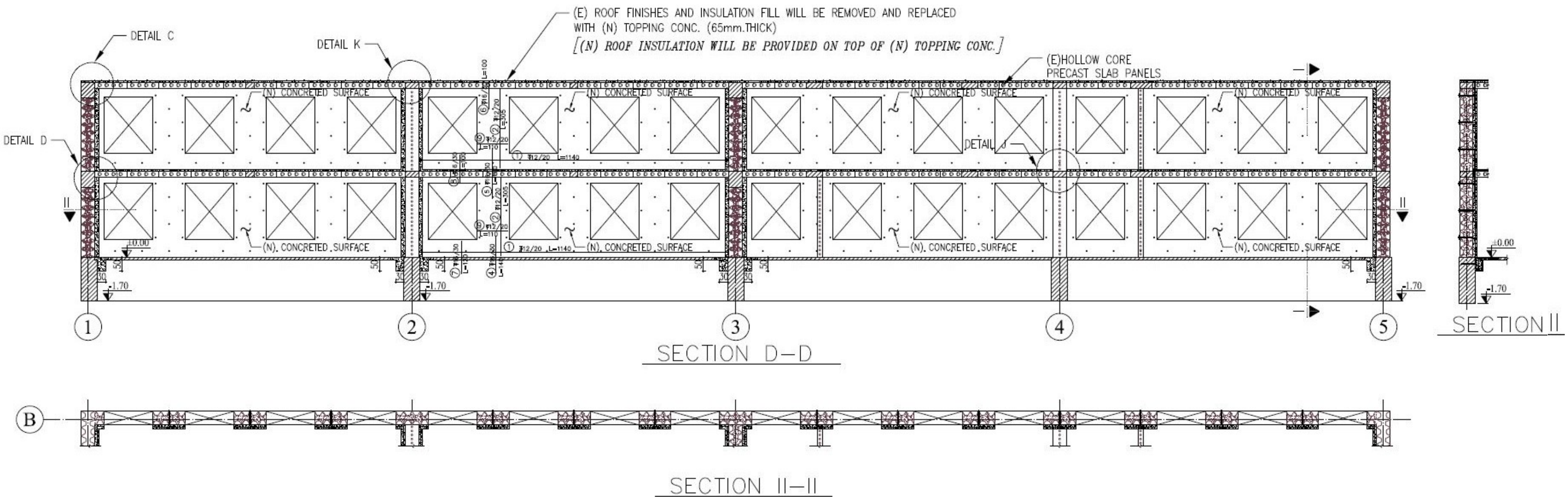


Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

Figure B-7 Typology A typical classroom - transverse section and details.

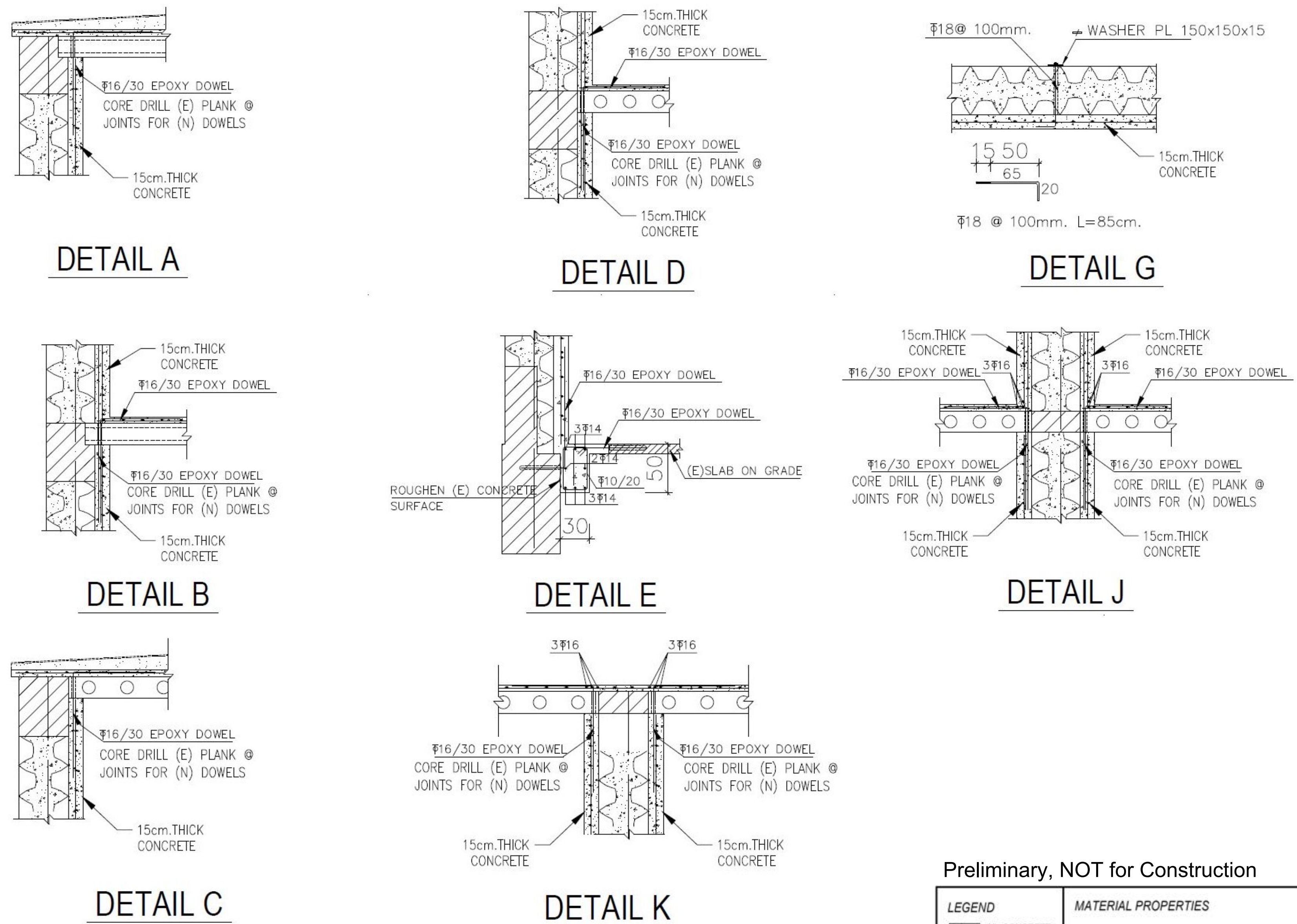
NOTE:
1. SEE DETAIL "H" FOR ADDITIONAL TRIM REINFORCEMENT AROUND WINDOW OPENINGS.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (fy)	A500C
(E) PEMZA		
(E) TUFA		

Figure B-8 Typology A typical classroom - longitudinal section and details.



Preliminary, NOT for Construction

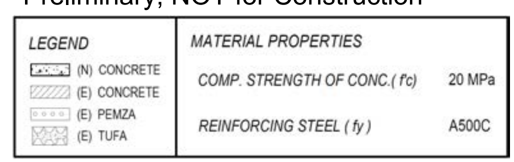
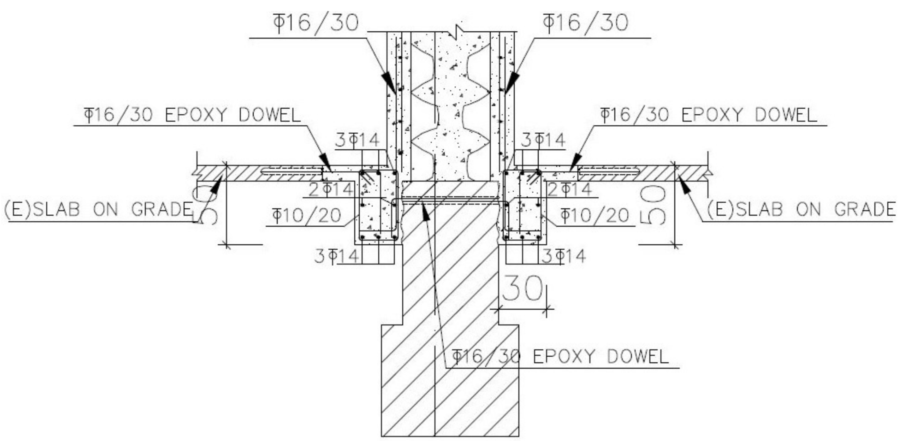
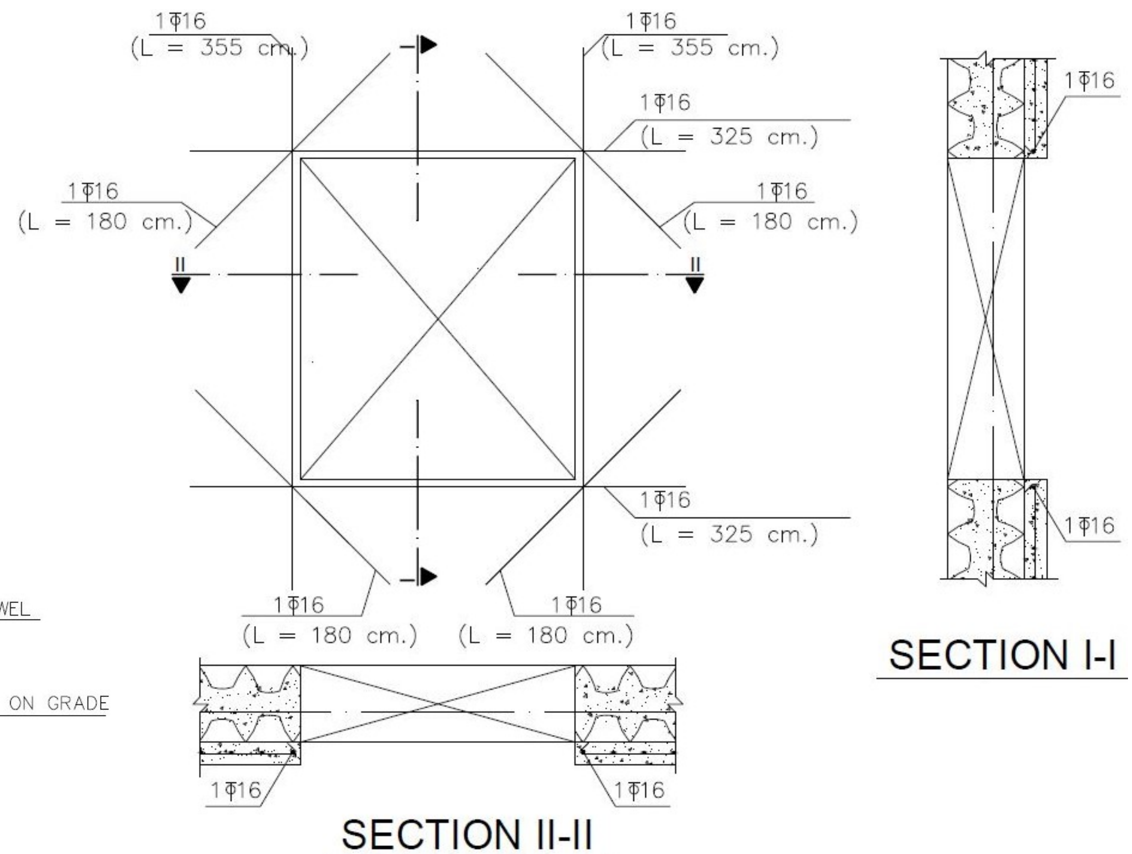


Figure B-9 Typology A typical classroom - typical details.



DETAIL F



DETAIL H
(TYPICAL TRIM REINFORCEMENT)

Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

Figure B-10 Typology A typical classroom - typical details.

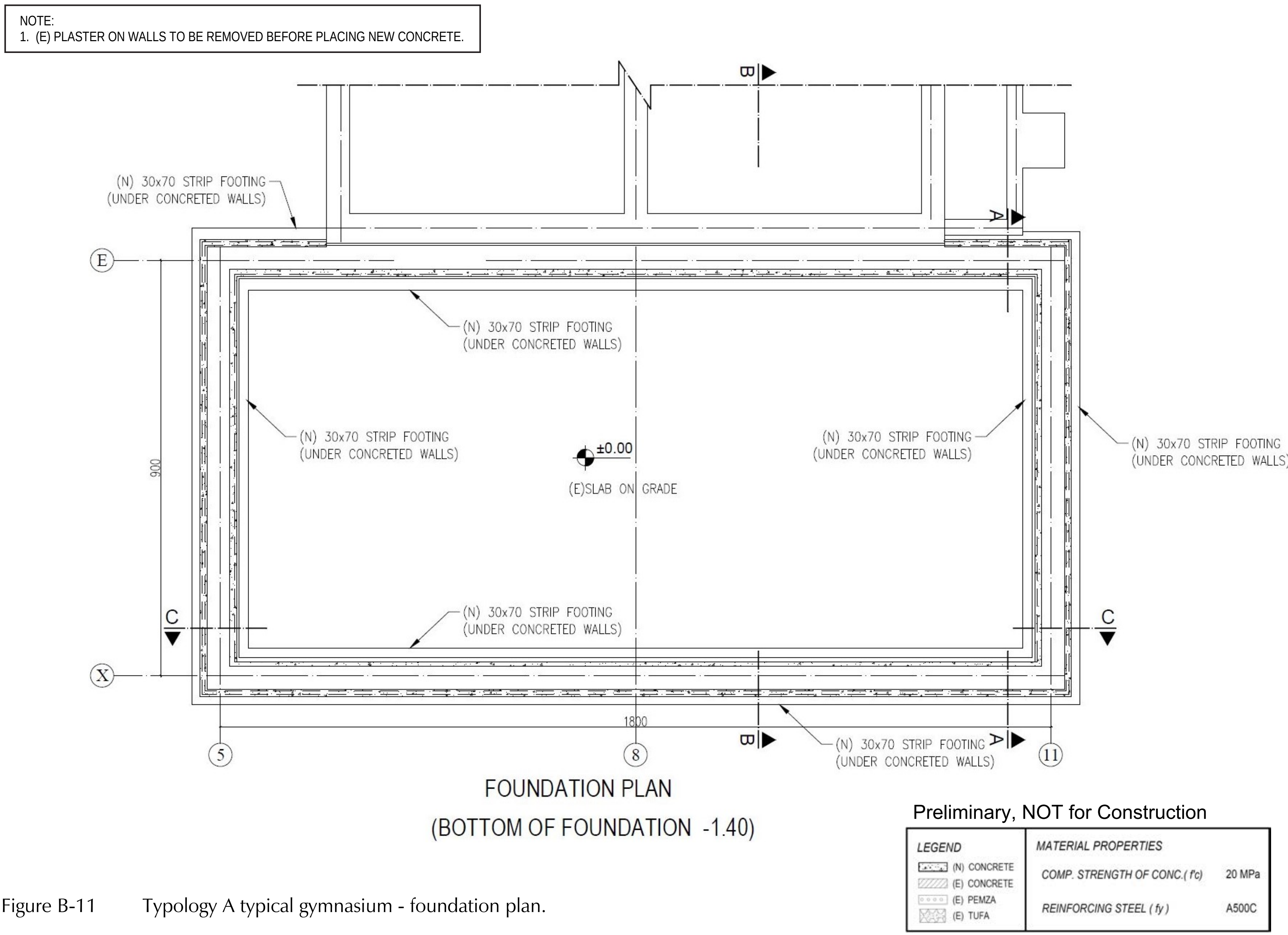
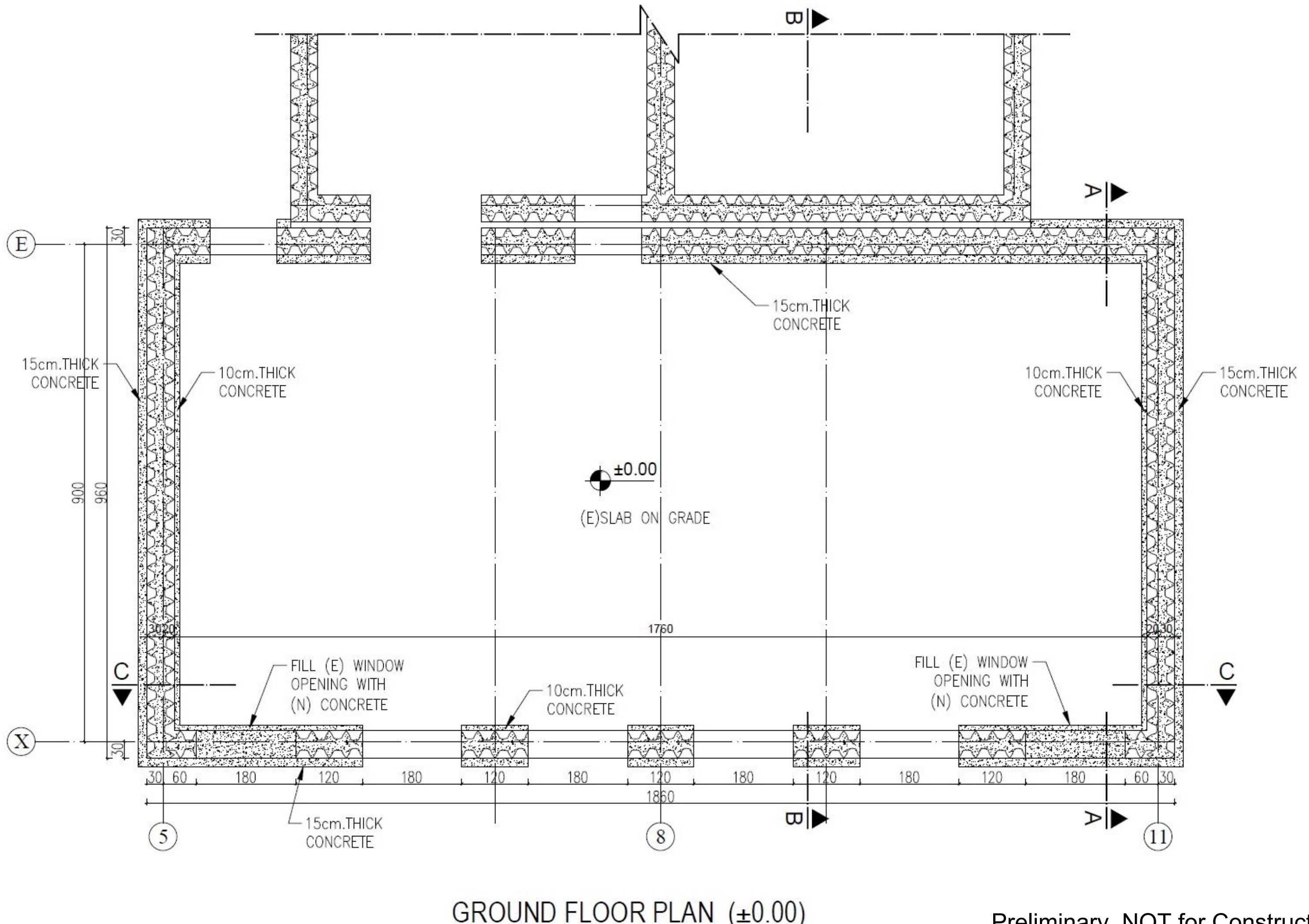


Figure B-11 Typology A typical gymnasium - foundation plan.

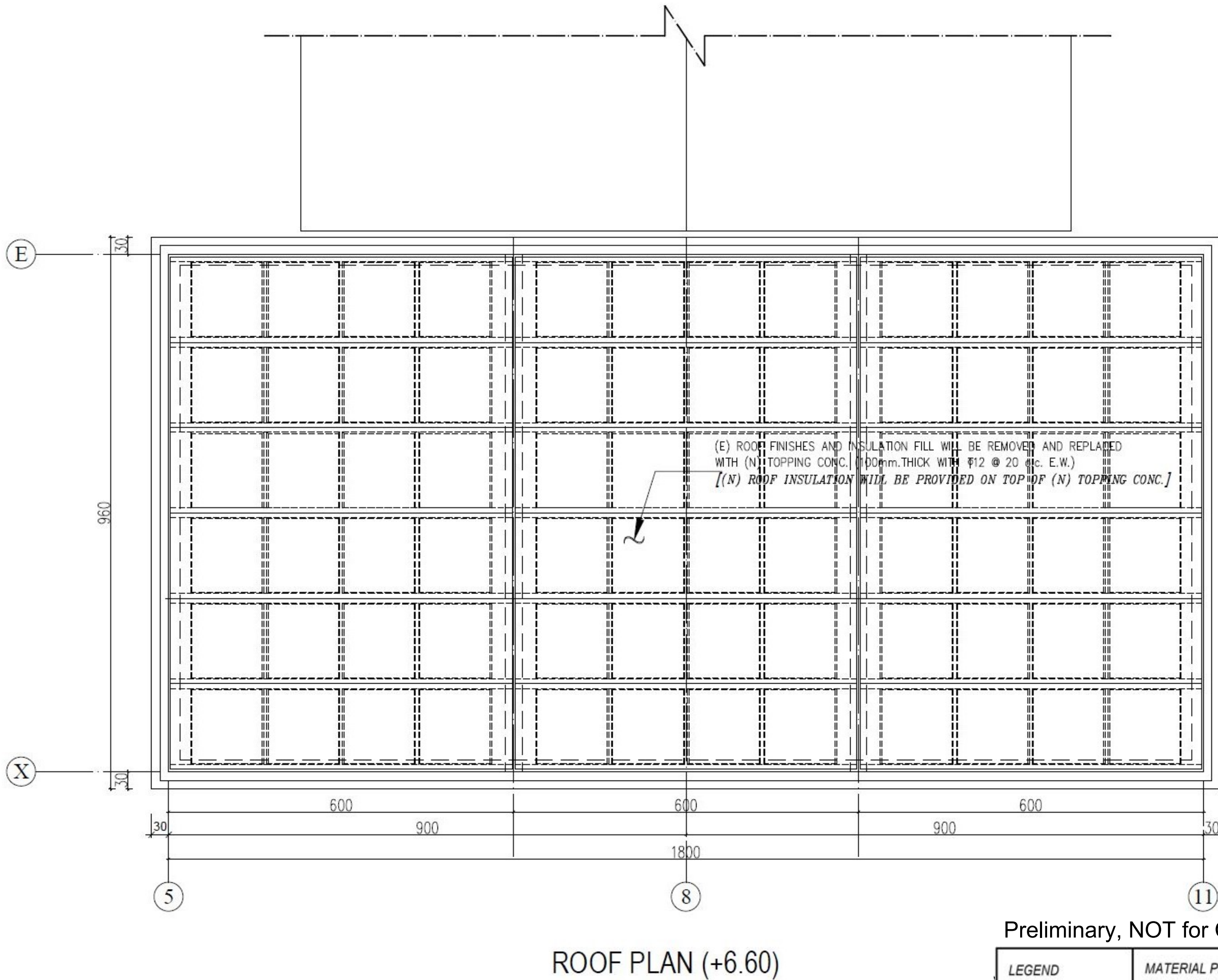
NOTE:
1. (E) PLASTER ON WALLS TO BE REMOVED BEFORE PLACING NEW CONCRETE.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

Figure B-12 Typology A typical gymnasium - ground floor plan.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (fy)	A500C
(E) PEMZA		
(E) TUFA		

Figure B-13 Typology A typical gymnasium - roof plan.

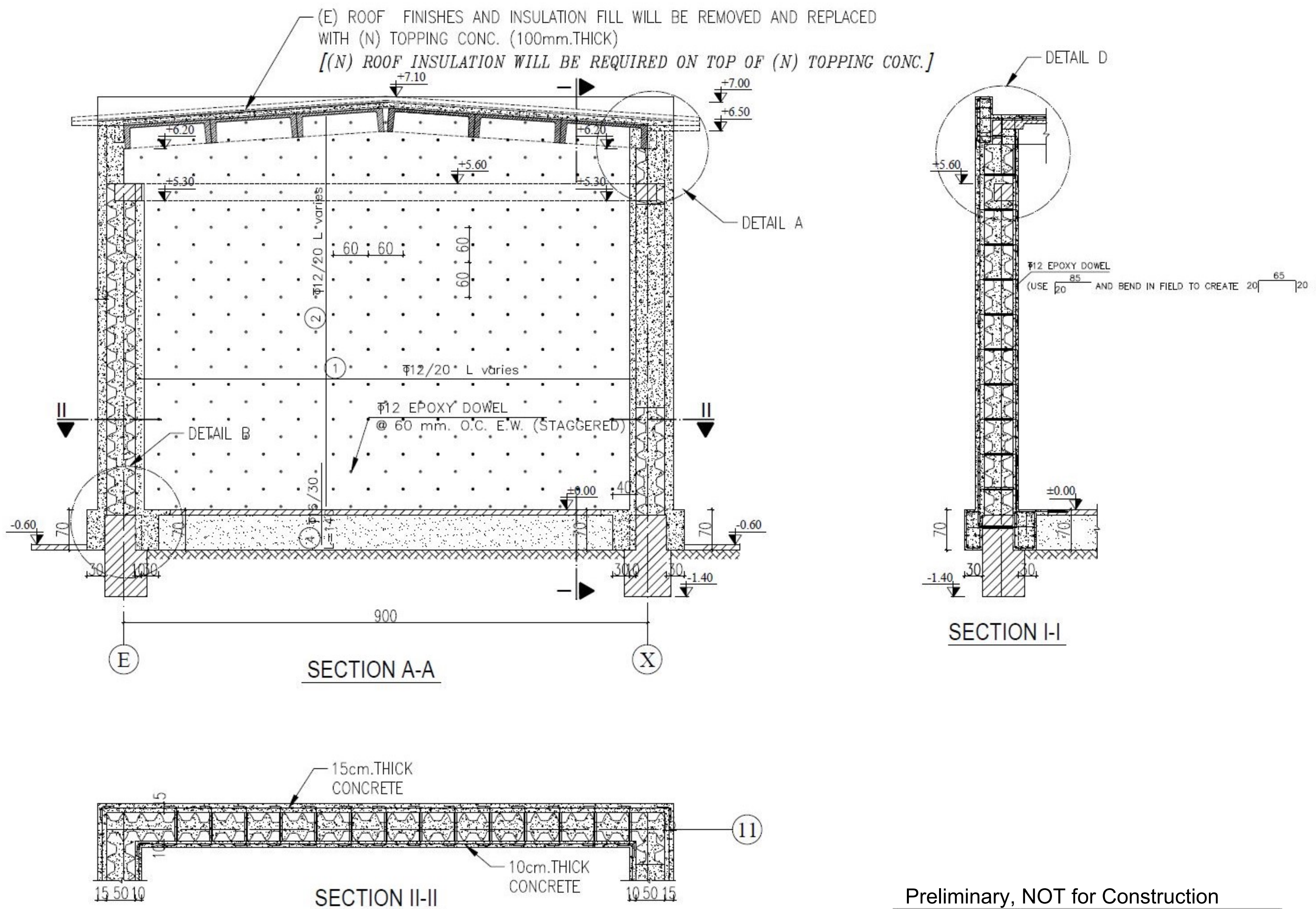
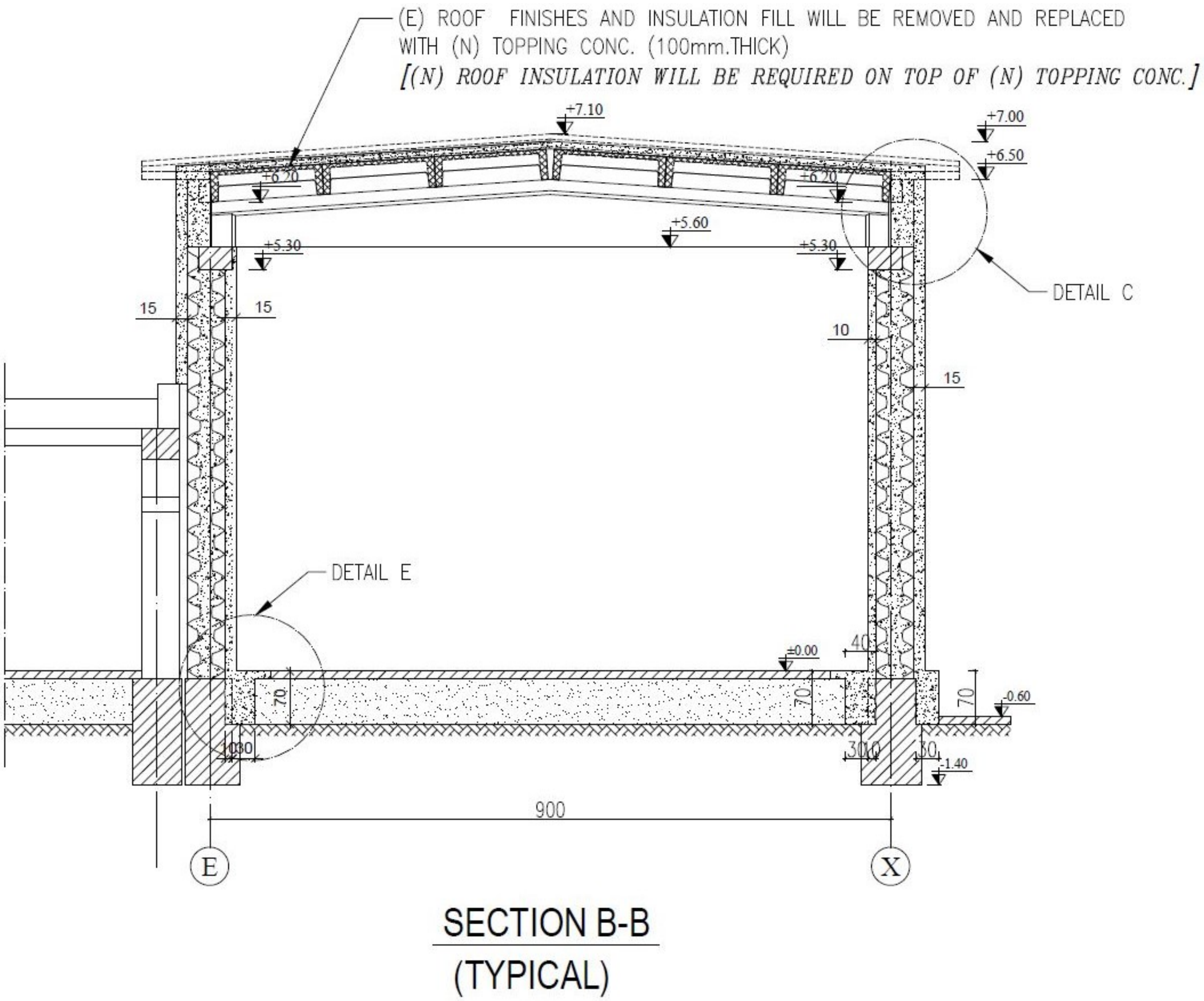


Figure B-14 Typology A typical gymnasium - transverse section and details.

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

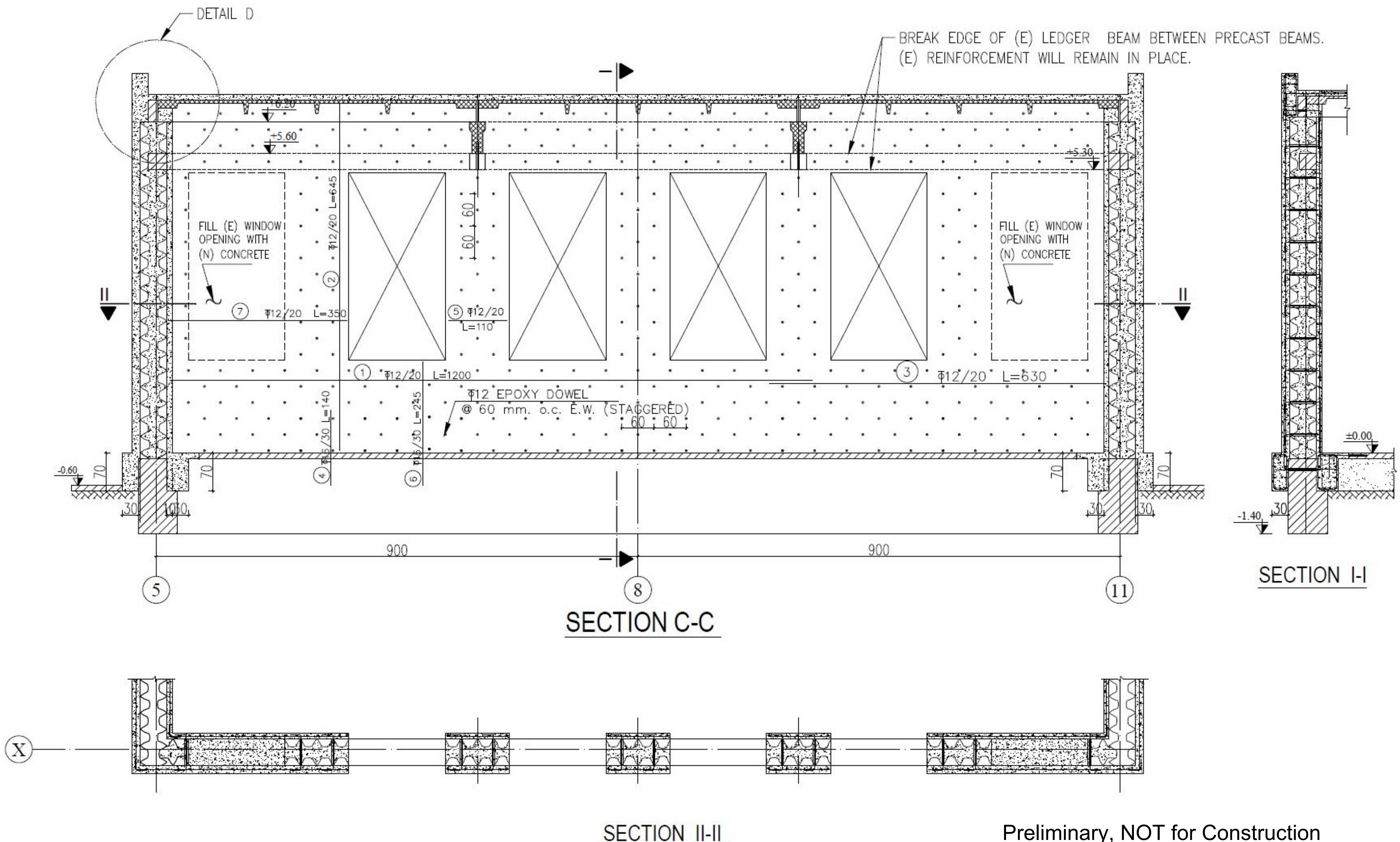


Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

Figure B-15 Typology A typical gymnasium - transverse section.

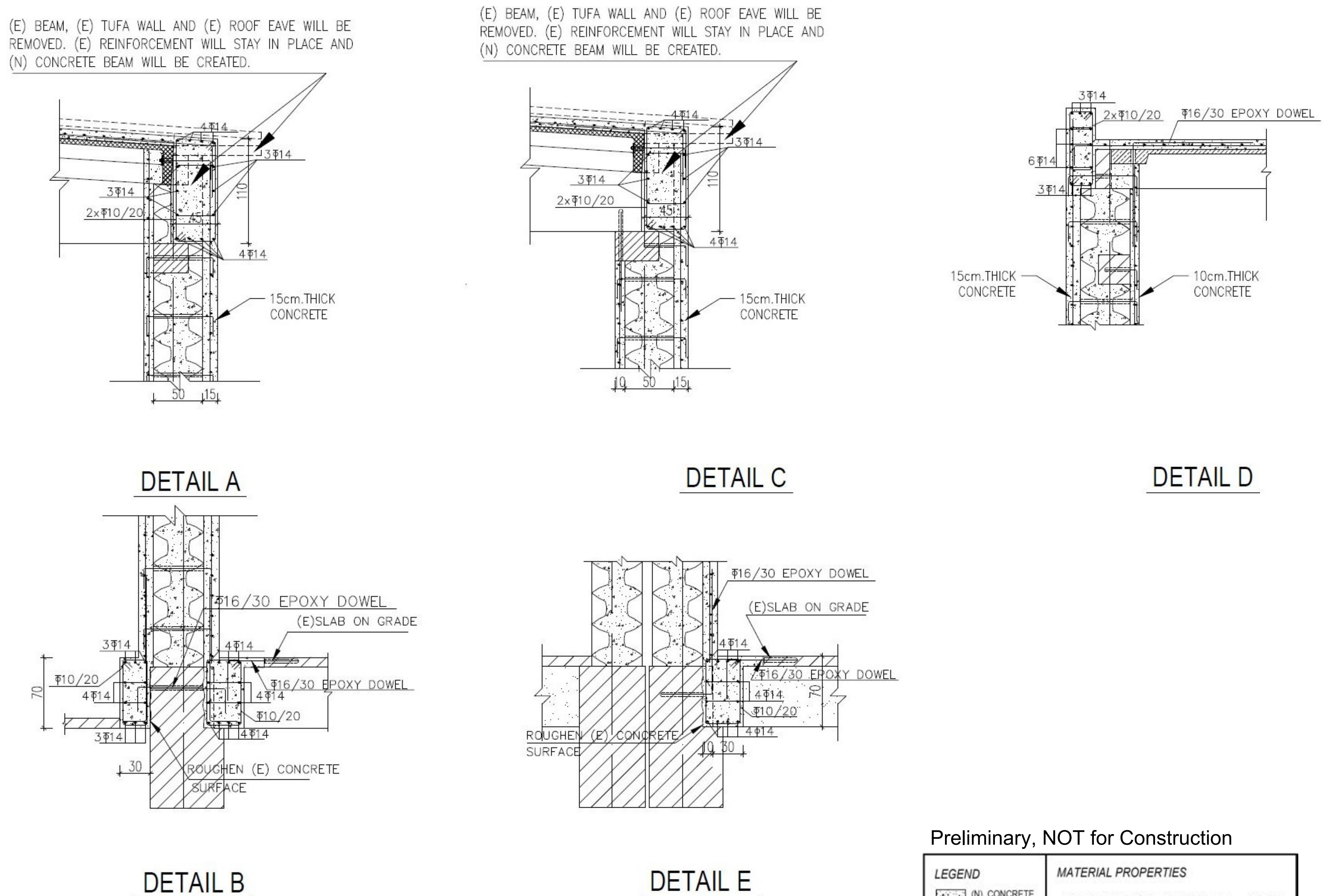
NOTE:
1. SEE DETAIL “F” FOR ADDITIONAL TRIM REINFORCEMENT AROUND WINDOW OPENINGS.
2. SEE DETAIL “G” FOR FILLING WINDOW OPENINGS.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE		
(E) PEMZA	REINFORCING STEEL (fy)	A500C
(E) TUFA		

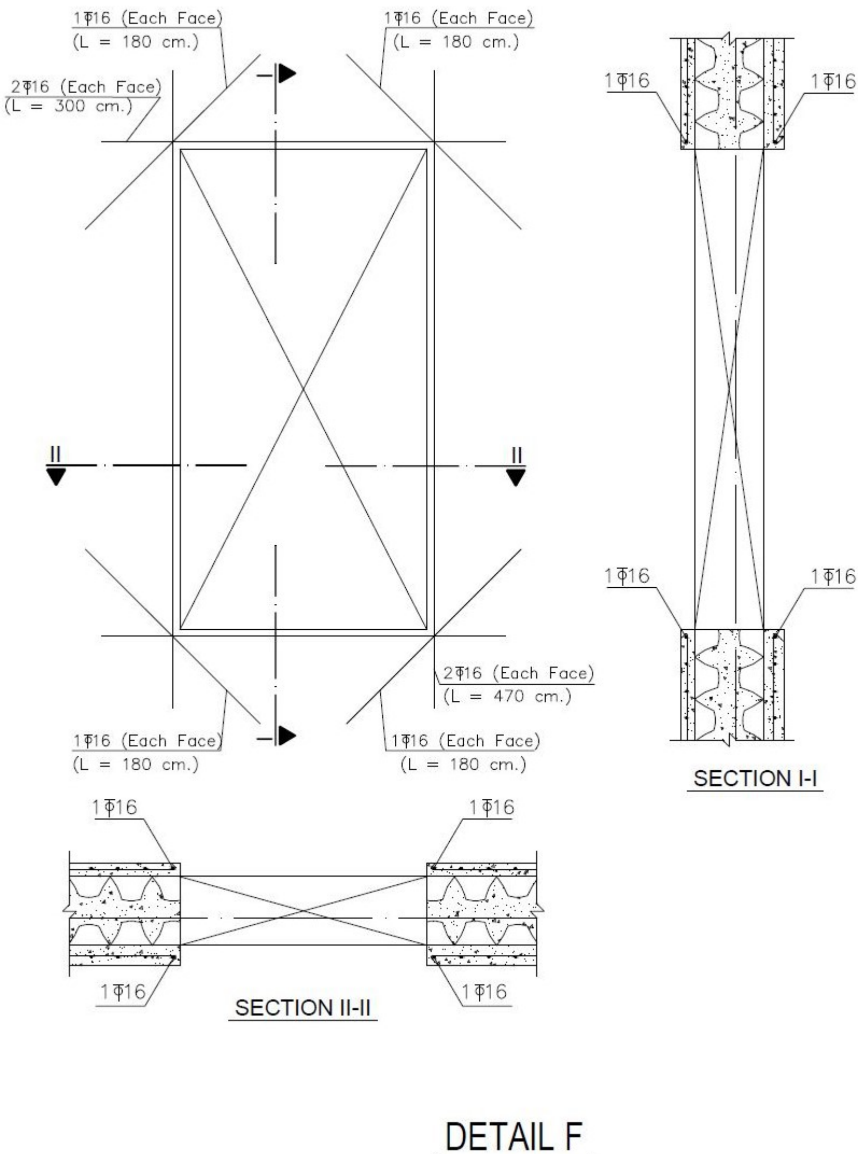
Figure B-16 Typology A typical gymnasium - longitudinal section and details.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC.(f'c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (fy)	A500C
(E) PEMZA		
(E) TUFA		

Figure B-17 Typology A typical gymnasium - typical details.



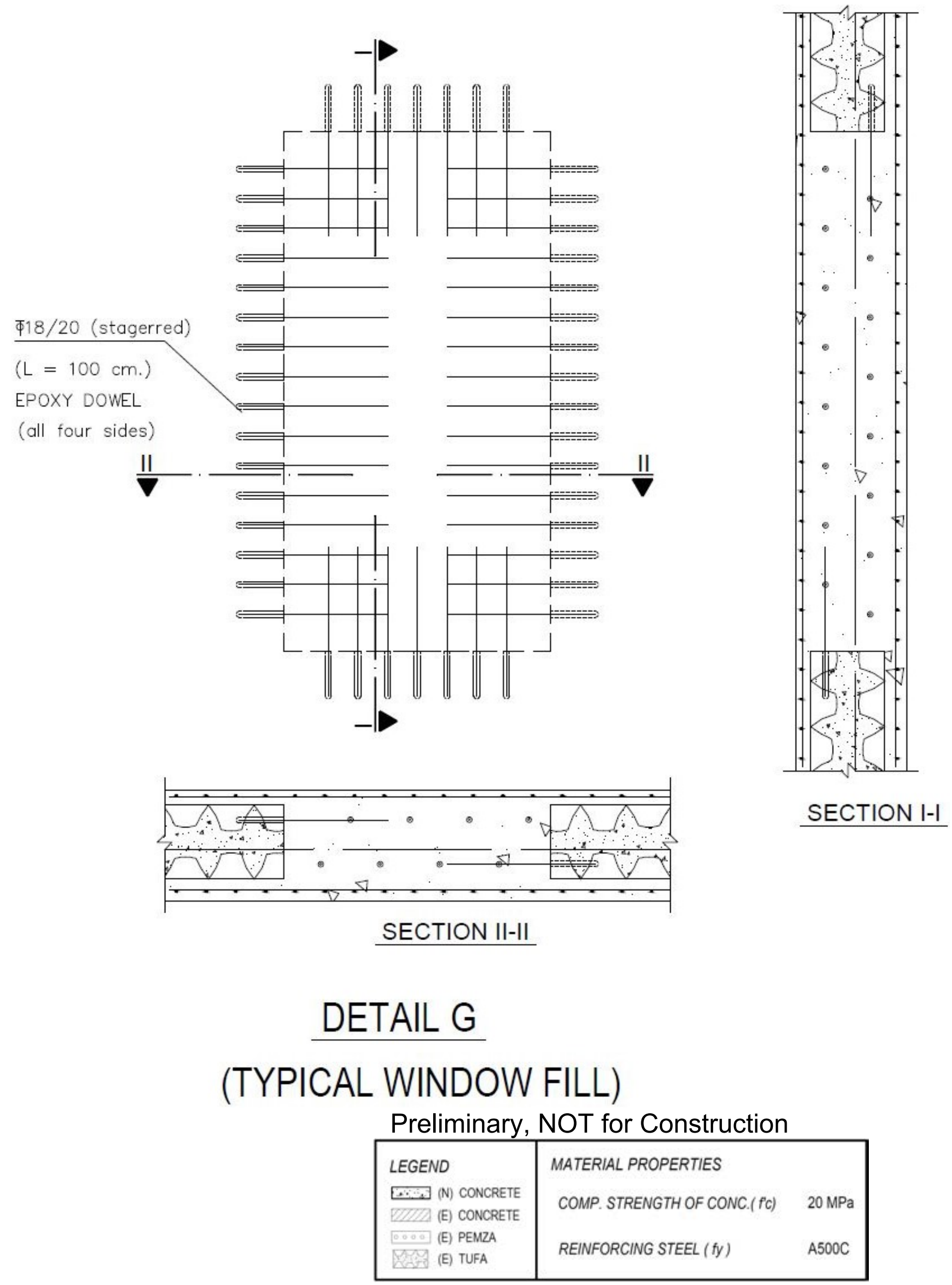


Figure B-18 Typology A typical gymnasium - typical details.

Appendix C
Conceptual Seismic Retrofit for Typology D-1 Buildings

This Appendix provides a structural narrative, plans, and typical details for conceptual seismic retrofit of Typology D-1 typical classroom and gymnasium buildings. Conceptual seismic retrofit plans and details provided in this appendix are summarized in Table C-1.

Table C-1 Conceptual Seismic Retrofit Drawings for Typology D-1 Buildings

Figure Number	*Figure Title*	*Page Number(s)*
C-1	Typology D-1 typical classroom - foundation plan	C-5
C-2	Typology D-1 typical classroom - ground floor plan	C-6
C-3	Typology D-1 typical classroom - second floor plan	C-7
C-4	Typology D-1 typical classroom - roof plan	C-8
C-5	Typology D-1 typical classroom - typical details	C-9
C-6	Typology D-1 typical gymnasium - foundation plan	C-10
C-7	Typology D-1 typical gymnasium - ground floor plan	C-11
C-8	Typology D-1 typical gymnasium - mezzanine floor plan	C-12
C-9	Typology D-1 typical gymnasium - roof plan	C-13
C-10	Typology D-1 typical gymnasium - typical details	C-14

C.1 Structural Narrative – Typology D-1 Typical Classroom Building

The steps for construction of conceptual seismic retrofit of Typology D-1 typical classroom buildings are as follows:

- Identify and demolish all interior precast concrete and masonry partitions that are non-load bearing, and will not be used as a back-form for new reinforced concrete shear walls.
- Prepare existing surfaces of precast concrete plank floor and roof systems by removal of nonstructural concrete, grout, roofing, and other finish materials. Prepare surfaces to receive new topping slab by chipping and sand-blasting to a clean and rough condition.
- At locations of new shear walls, remove existing exterior precast wall panels.
- Concurrent with the removal of exterior precast wall panels at new shear walls, inspect and evaluate the adequacy and condition of the precast panels that are to remain, including reinforcement, supporting structure, and connections between the panels and the structure. If the panels,

connections, or supporting structure are not adequate to resist in-plane and out-of-plane seismic loads, all panels should be removed and replaced with modern lightweight cold-formed steel studs and curtain wall construction.

- Supplement and reinforce existing foundations with new reinforced concrete foundation strengthening that extends to bottom of existing footings.
- Provide sufficient dowels through existing precast beams, precast columns, and foundation elements to provide continuity for transferring all shear wall and collector forces through existing concrete elements.
- Provide temporary support and shoring of floor framing as necessary to facilitate the construction of new shear walls.
- Place new reinforced concrete shear walls on the centerline of existing framing lines with concrete of sufficient strength (minimum of 20 MPa; cylindrical strength), thickness (minimum of 30 cm), and reinforcement (15 cm maximum spacing each way for reinforcing bars) to resist in-plane and out-of-plane seismic loads. All reinforcing steel must be adequately chaired within forms and held in position during placement of concrete.
- Provide new reinforced concrete collectors below the existing floor framing along shear wall lines to deliver seismic loads to the new shear walls.
- Construct a cast-in-place reinforced concrete topping slab using concrete of sufficient thickness, and reinforcement on the surface of all precast floor and roof planks. The thickness of the topping slab should account for variations in the elevation of the top of floor framing so that adequate diaphragm shear strength is provided at critical locations (for example, the 80 mm specified thickness provides 65 mm minimum thickness over precast beams). Lightweight concrete may be used for topping slabs to reduce the added weight. Provide epoxy dowels between the new topping slab and the precast planks. Provide reinforcing dowels between the new shear walls, collectors, and new topping slabs to transfer in-plane and out-of-plane seismic loads between the walls and the diaphragms.
- For architectural continuity at locations of new exterior shear walls, replicate the appearance of the adjacent precast wall panels using modern lightweight cold-formed steel studs and curtain wall construction.
- Replace roofing and floor finishes with new lightweight materials over the reinforced concrete topping slab.
- Replace demolished masonry partitions with modern lightweight cold-formed steel studs and gypsum wallboard. Construct new lightweight interior partitioning between classrooms and corridors, as needed.
- Clear, widen (as necessary), and protect (with appropriate architectural details) all anti-seismic joints between building wings.

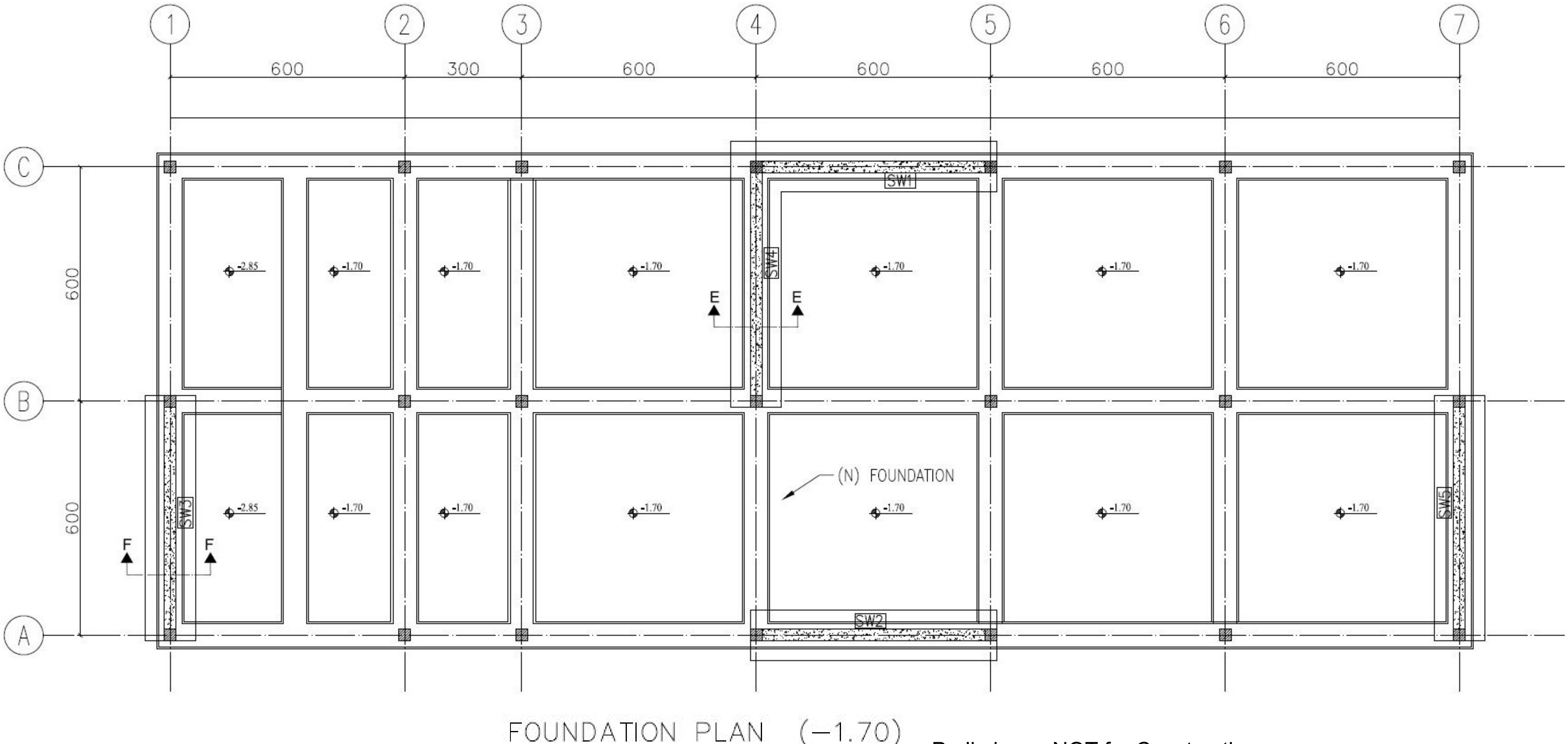
C.2 Structural Narrative – Typology D-1 Typical Gymnasium Building

The steps for construction of conceptual seismic retrofit of Typology D-1 typical gymnasium buildings are as follows:

- Prepare existing surfaces of precast concrete plank floor and roof systems by removal of nonstructural concrete, grout, roofing, and other finish materials. Prepare surfaces to receive new topping slab by chipping and sand-blasting to a clean and rough condition.
- At locations of new shear walls, remove existing exterior precast wall panels.
- Concurrent with the removal of exterior precast wall panels at new shear walls, inspect and evaluate the adequacy and condition of the precast panels that are to remain, including reinforcement, supporting structure, and connections between the panels and the structure. If the panels, connections, or supporting structure are not adequate to resist in-plane and out-of-plane seismic loads, all panels should be removed and replaced with modern lightweight cold-formed steel studs and curtain wall construction.
- Supplement and reinforce existing foundations with new reinforced concrete foundation strengthening that extends to bottom of existing footings.
- Provide sufficient dowels through existing precast beams, precast columns, and foundation elements to provide continuity for transferring all shear wall and collector forces through existing concrete elements.
- Provide temporary support and shoring of floor framing as necessary to facilitate the construction of new shear walls.
- Place new reinforced concrete shear walls on the centerline of existing framing lines with concrete of sufficient strength (minimum of 20 MPa; cylindrical strength), thickness (minimum of 30 cm), and reinforcement (15 cm maximum spacing each way for reinforcing bars) to resist in-plane and out-of-plane seismic loads. All reinforcing steel must be adequately chaired within forms and held in position during placement of concrete.
- Provide new reinforced concrete collectors below the existing roof and floor framing along shear wall lines to deliver seismic loads to the new shear walls.
- Construct a cast-in-place reinforced concrete topping slab using concrete of sufficient thickness (100 mm at the roof; 80 mm at the mezzanine), and reinforcement (15 cm maximum spacing each way for reinforcing bars) on the surface of precast floor and roof framing. Lightweight concrete may be used for topping slabs to reduce the added weight. Provide epoxy dowels between the new topping slab and the precast framing. Provide reinforcing dowels between the new shear walls, collectors, and new topping slabs to transfer in-plane and out-of-plane seismic loads between the walls and the diaphragms.
- For architectural continuity at locations of new exterior shear walls, replicate the appearance of the adjacent precast wall panels using modern lightweight cold-formed steel studs and curtain wall construction.

- Replace roofing and insulation with new lightweight materials, sloped to drain, over the reinforced concrete topping slab.
- Clear, widen (as necessary), and protect (with appropriate architectural details) all anti-seismic joints between building wings.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.

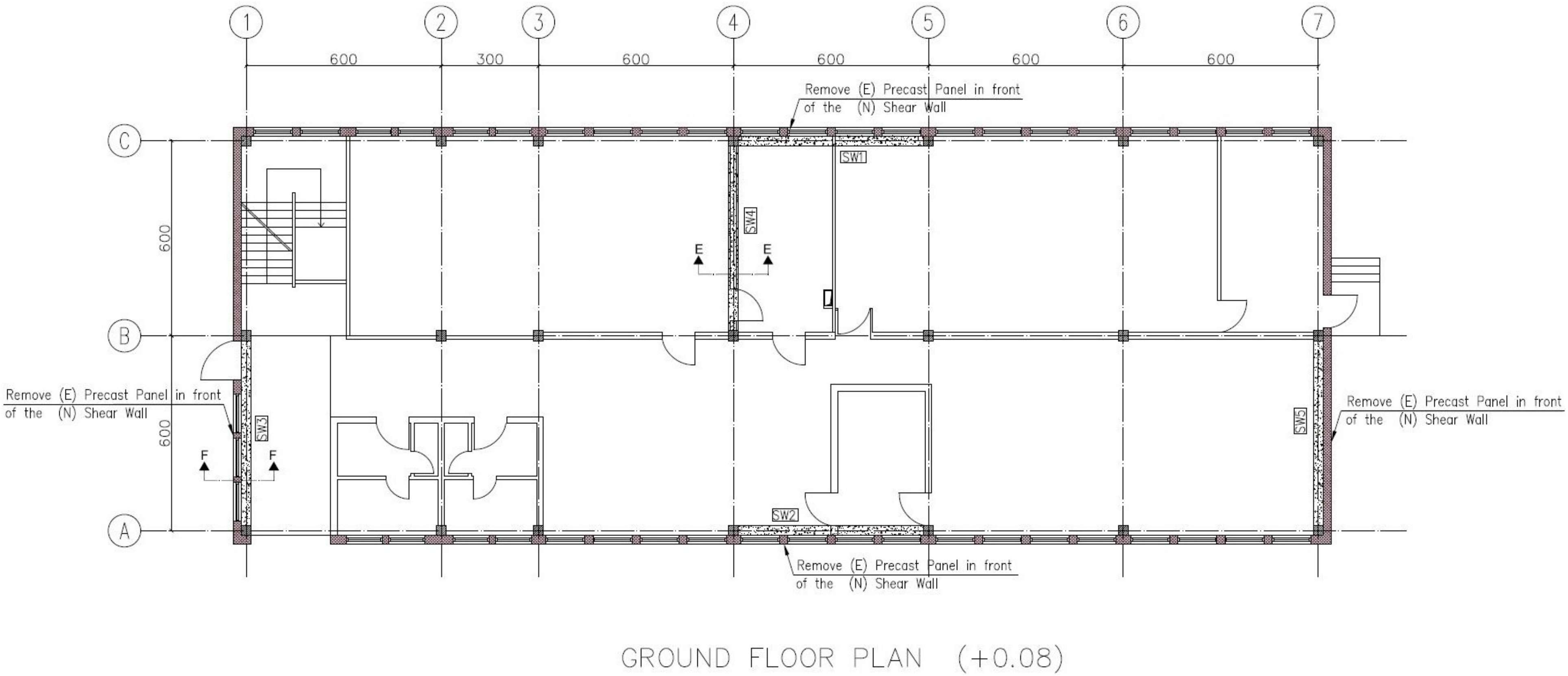


Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-1 Typology D-1 typical classroom - foundation plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.



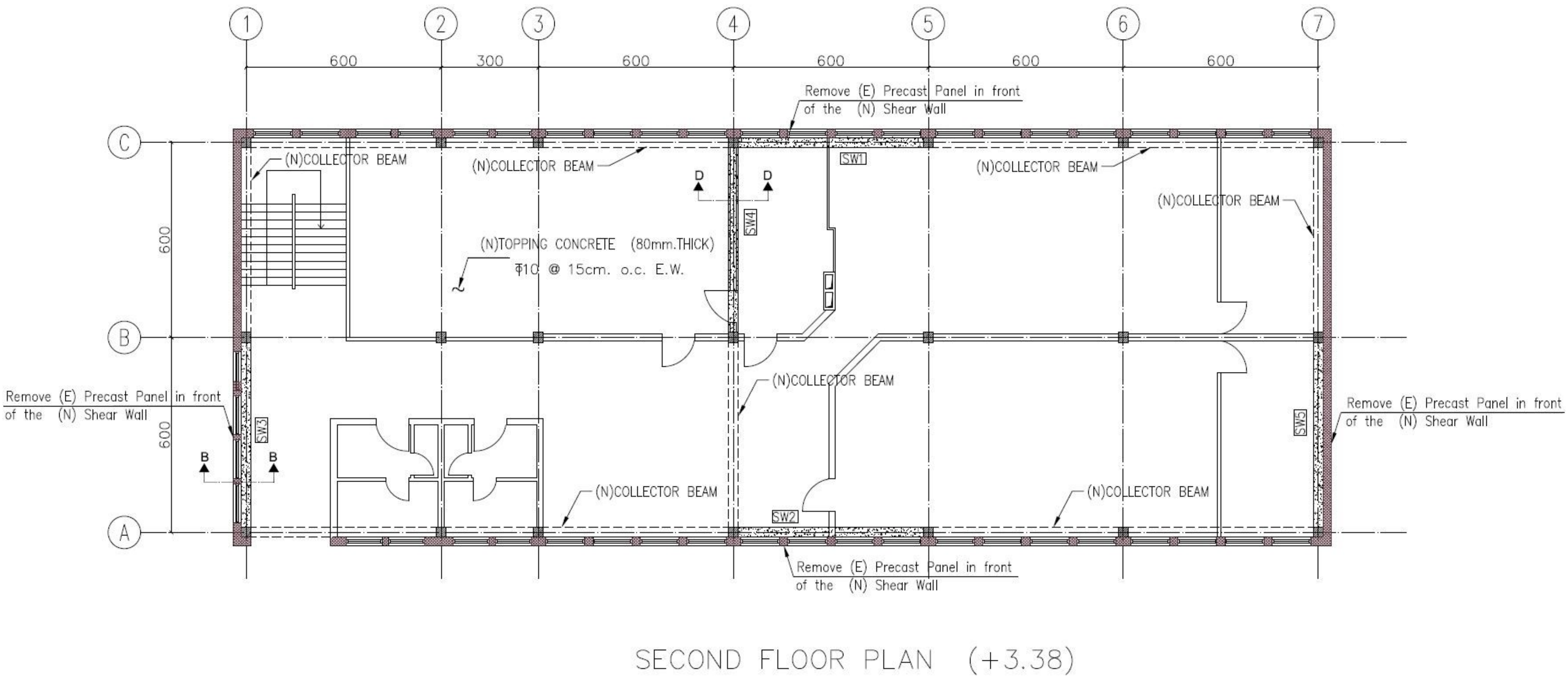
Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-2 Typology D-1 typical classroom - ground floor plan.

GENERAL NOTES:

1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.

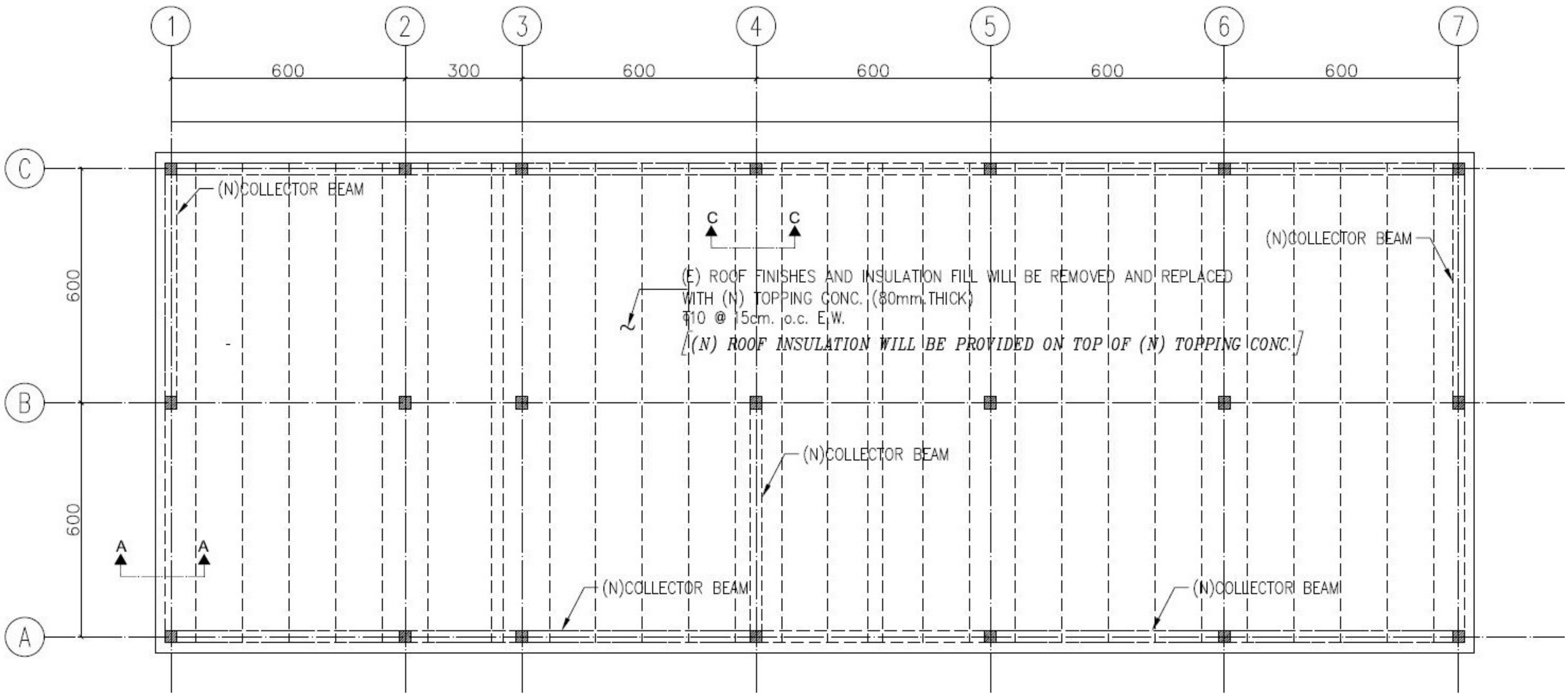


Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-3 Typology D-1 typical classroom - second floor plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.



ROOF PLAN (+6.68) Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-4 Typology D-1 typical classroom - roof plan.

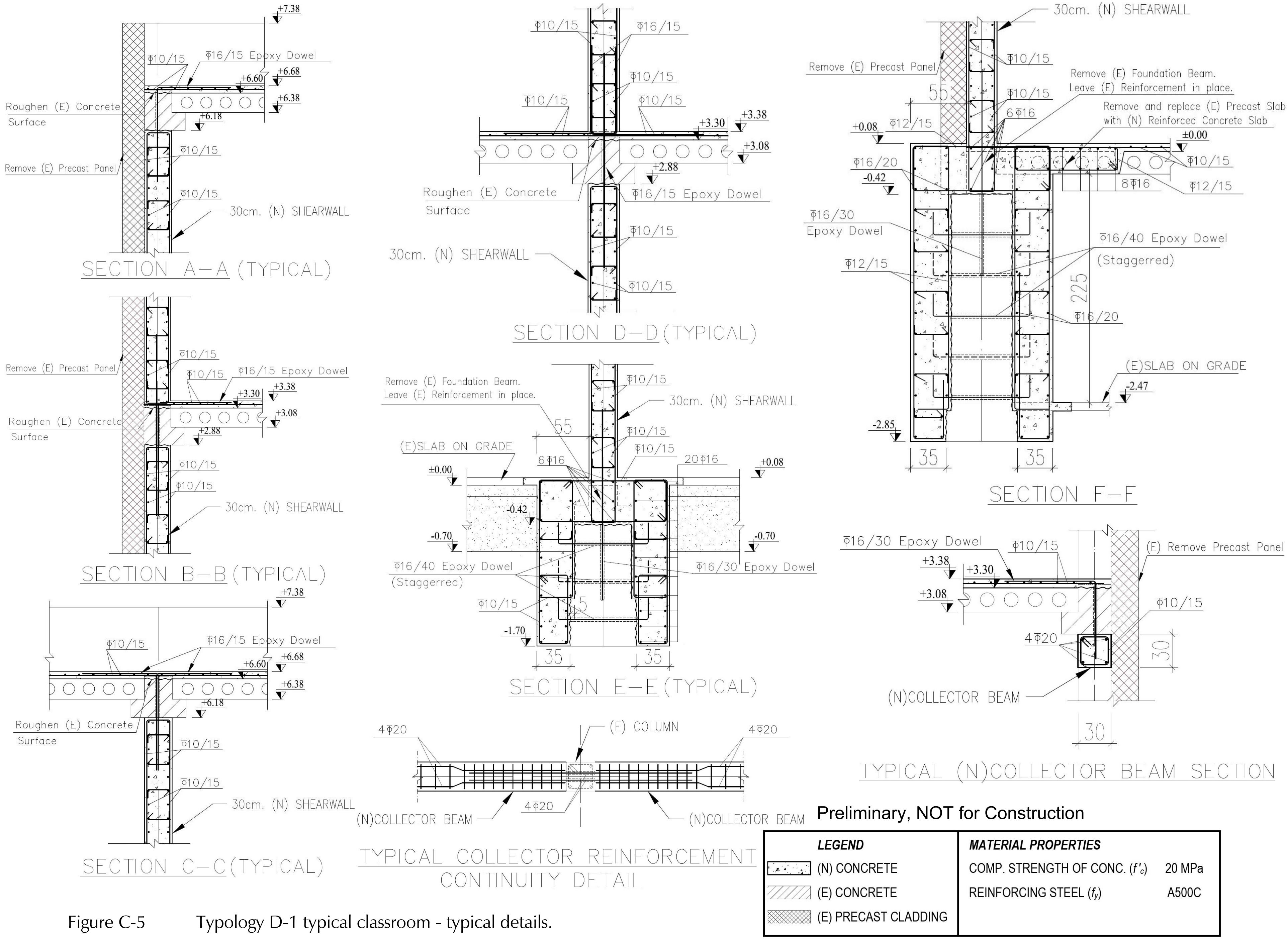
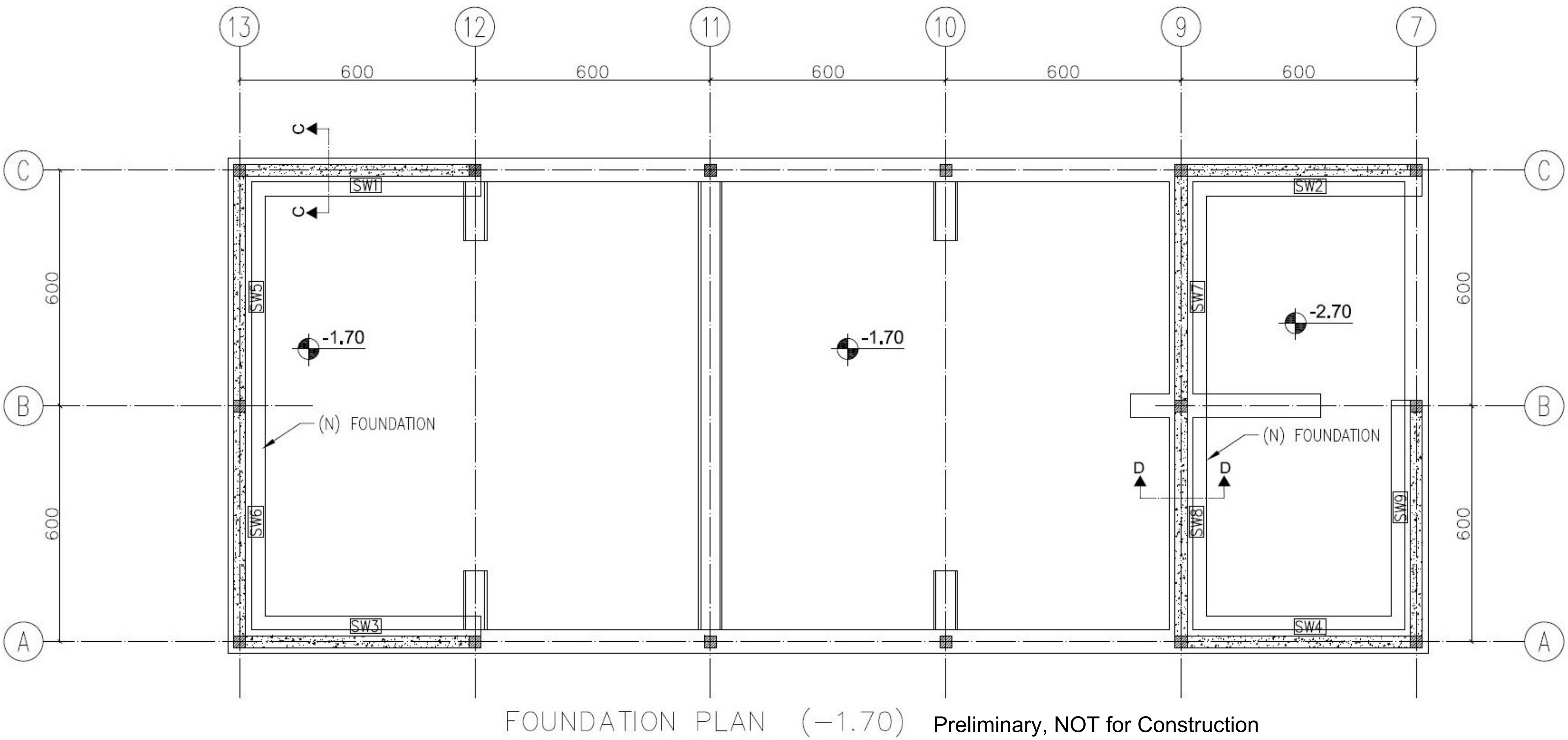


Figure C-5 Typology D-1 typical classroom - typical details.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.

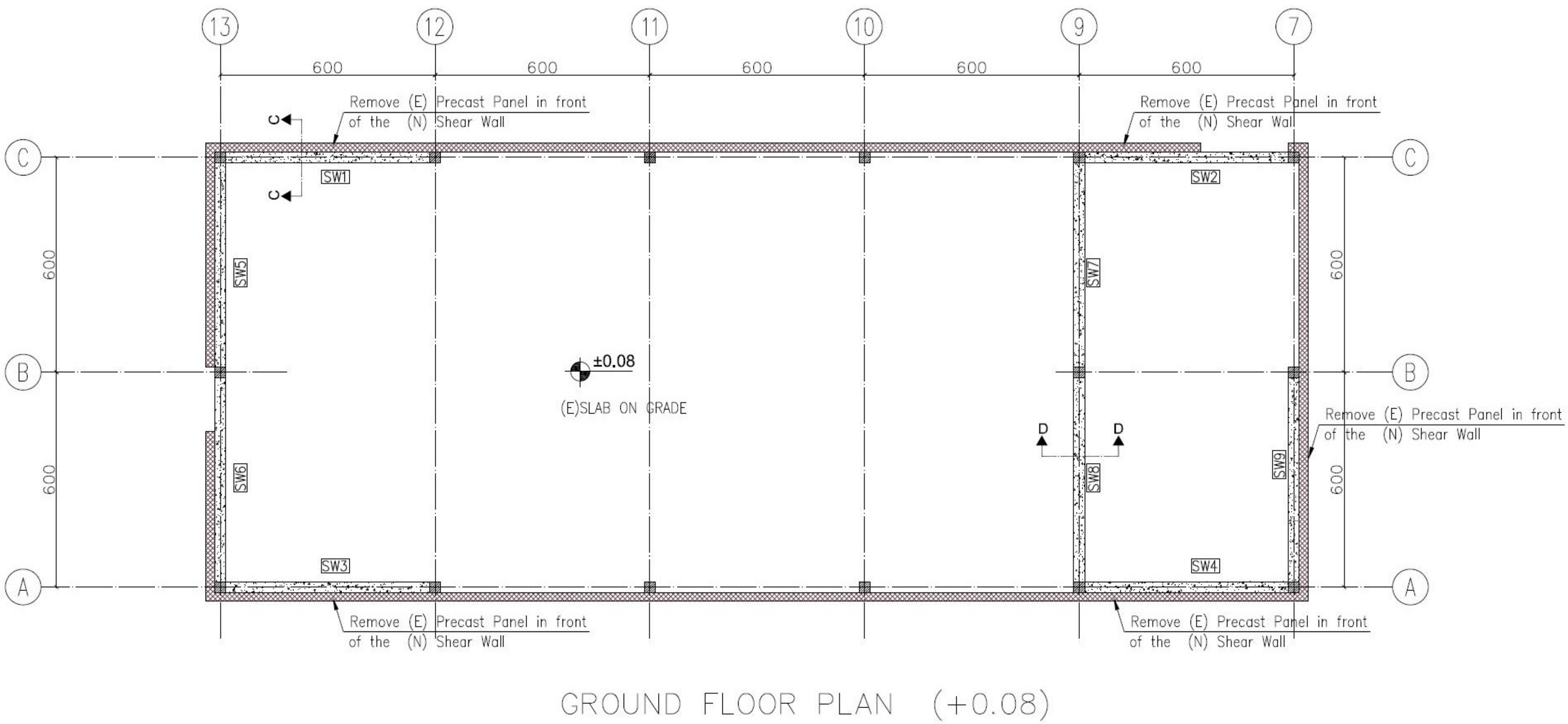


Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-6 Typology D-1 typical gymnasium - foundation plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.

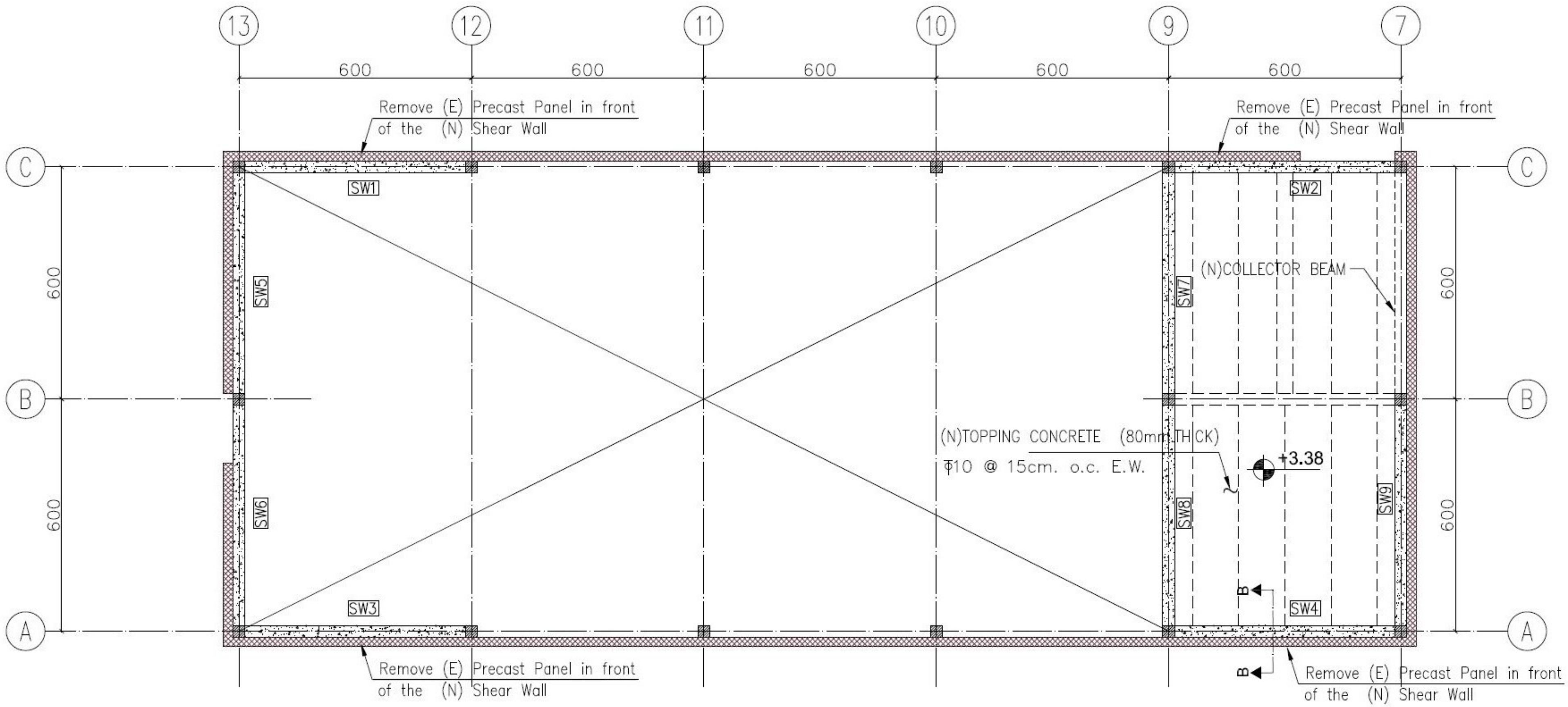


Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-7 Typology D-1 typical gymnasium - ground floor plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.



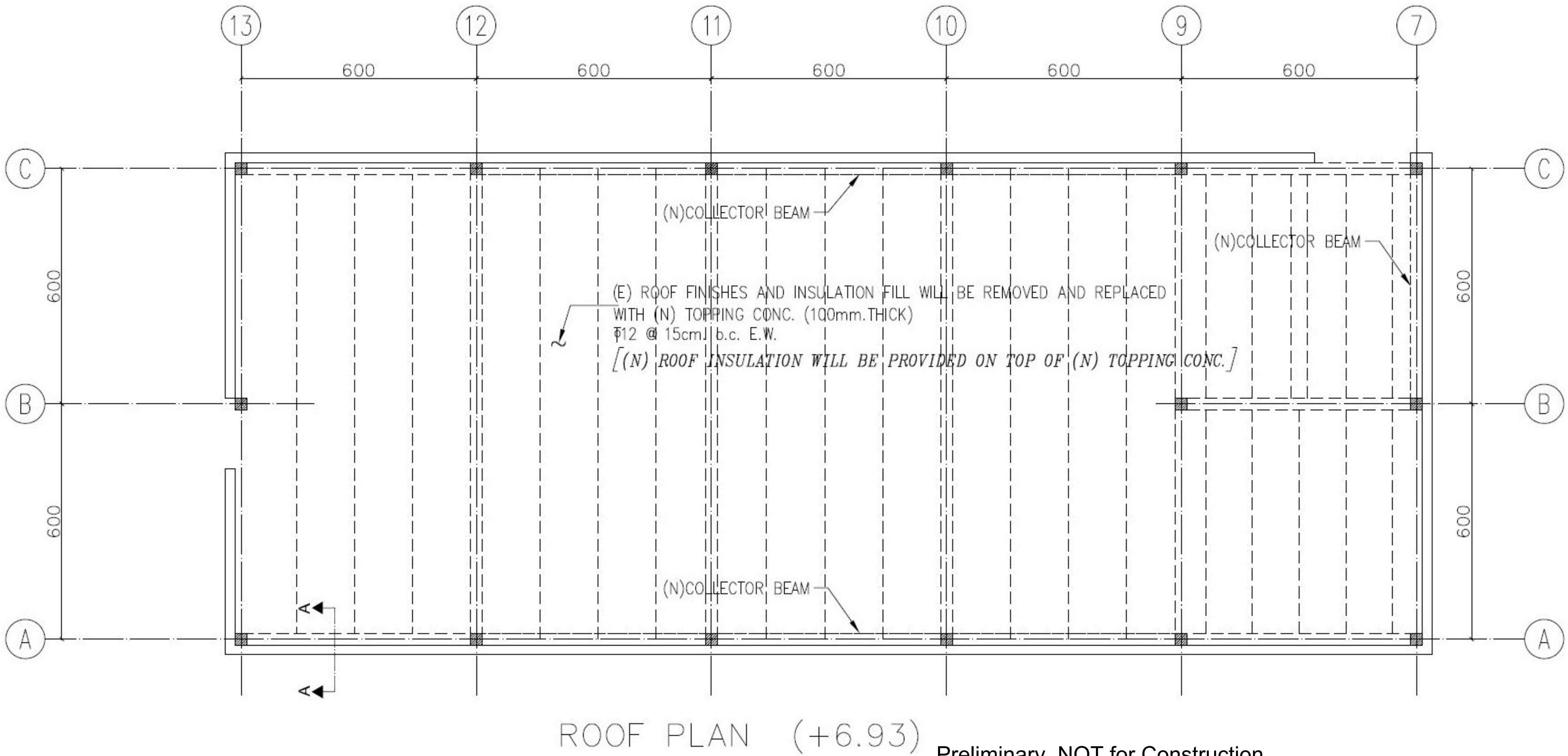
MEZZANINE FLOOR PLAN (+3.38)

Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-8 Typology D-1 typical gymnasium - mezzanine floor plan.

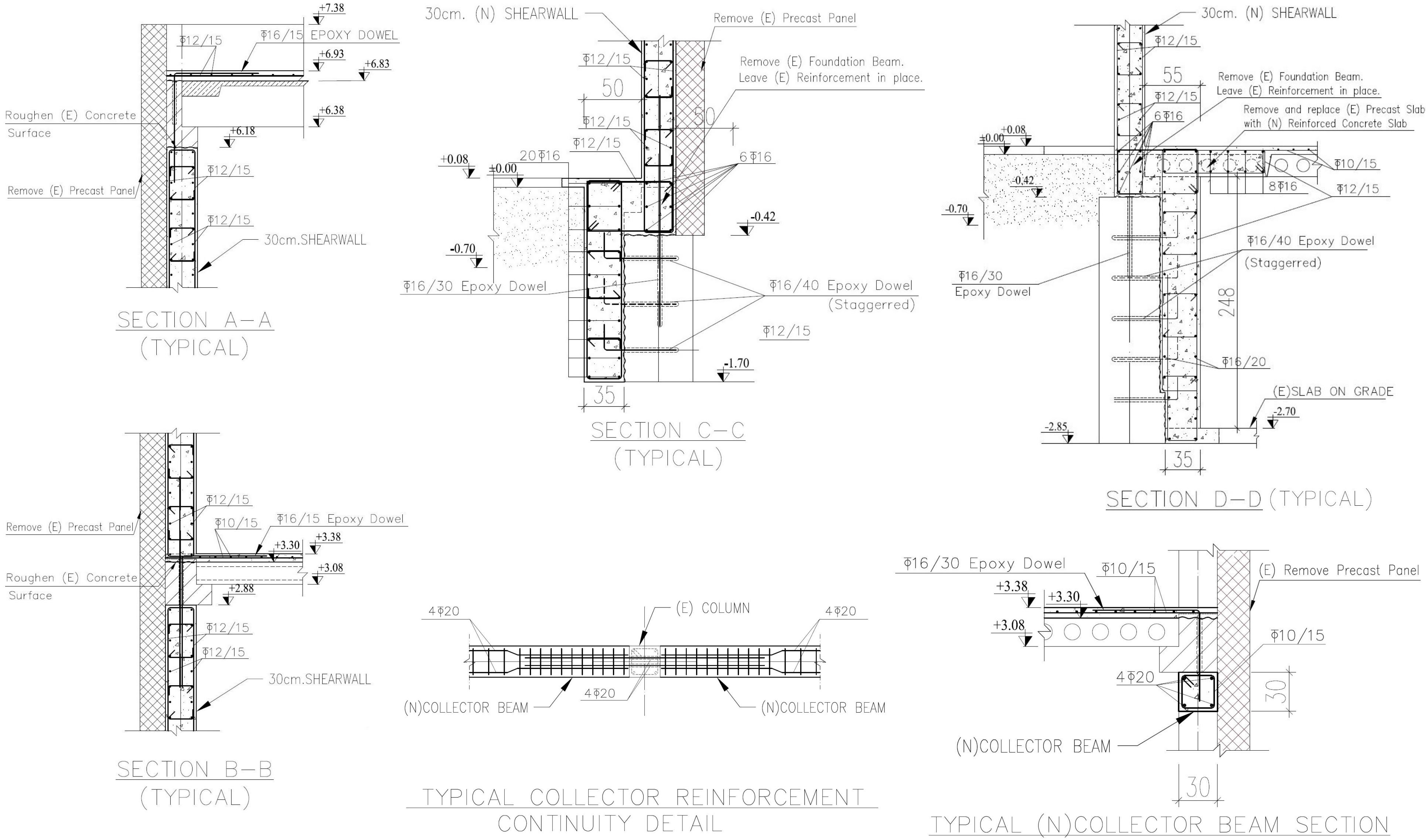
GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.



Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-9 Typology D-1 typical gymnasium - roof plan.



Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure C-10 Typology D-1 typical gymnasium - typical details.

Appendix D
Conceptual Seismic Retrofit for Typology D-2 Buildings

This Appendix provides a structural narrative, plans, and typical details for conceptual seismic retrofit of Typology D-2 typical classroom buildings. Typology D-2 gymnasium buildings are essentially identical to Typology D-1 gymnasiums. As a result, the structural narrative, plans, and typical details for conceptual seismic retrofit of Typology D-2 typical gymnasium buildings are the same as specified for Typology D-1 in Appendix C of these *Guidelines*. Conceptual seismic retrofit plans and details provided in this appendix are summarized in Table D-1.

Table D-1 Conceptual Seismic Retrofit Drawings for Typology D-2 Buildings

Figure Number	*Figure Title*	*Page Number(s)*
D-1	Typology D-2 typical classroom - foundation plan	D-4
D-2	Typology D-2 typical classroom - ground floor plan	D-5
D-3	Typology D-2 typical classroom - second floor plan	D-6
D-4	Typology D-2 typical classroom - third floor plan	D-7
D-5	Typology D-2 typical classroom - roof plan	D-8
D-6	Typology D-2 typical classroom - typical details	D-9
D-7	Typology D-2 typical classroom - typical details	D-10

D.1 Structural Narrative – Typology D-2 Typical Classroom Building

The steps for construction of conceptual seismic retrofit of Typology D-2 typical classroom buildings are provided below. They are similar to Typology D-1 retrofit measures, but differ in terms of the quantity and details of the work because of additional seismic demands associated with taller structures.

- Identify and demolish all interior precast concrete and masonry partitions that are non-load bearing, and will not be used as a back-form for new reinforced concrete shear walls.
- Prepare existing surfaces of precast concrete plank floor and roof systems by removal of nonstructural concrete, grout, roofing, and other finish materials. Prepare surfaces to receive new topping slab by chipping and sand-blasting to a clean and rough condition.
- At locations of new shear walls, remove existing exterior precast wall panels.
- Concurrent with the removal of exterior precast wall panels at new shear walls, inspect and evaluate the adequacy and condition of the precast panels that are to remain, including reinforcement,

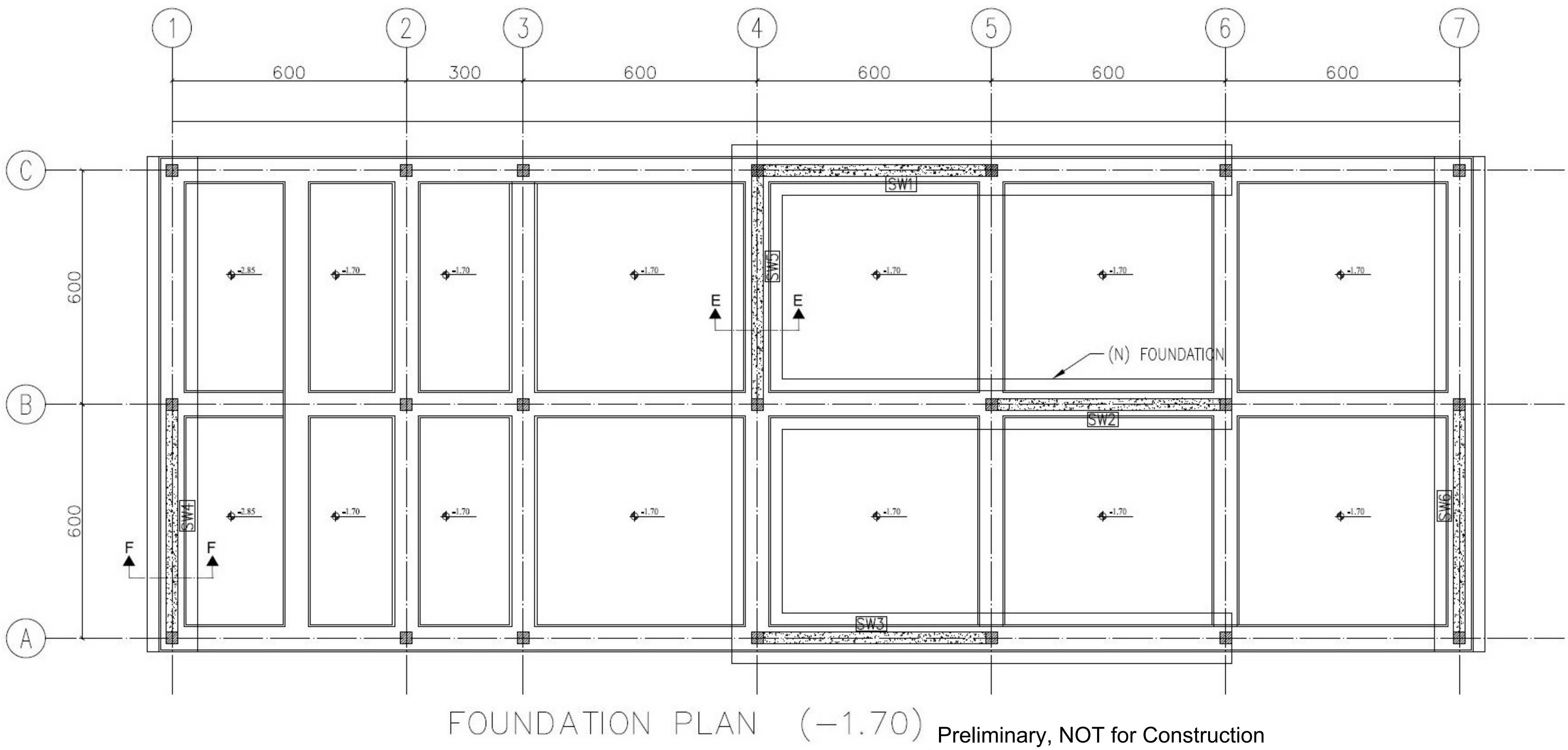
supporting structure, and connections between the panels and the structure. If the panels, connections, or supporting structure are not adequate to resist in-plane and out-of-plane seismic loads, all panels should be removed and replaced with modern lightweight cold-formed steel studs and curtain wall construction.

- Supplement and reinforce existing foundations with new reinforced concrete foundation strengthening that extends to bottom of existing footings.
- Provide sufficient dowels through existing precast beams, precast columns, and foundation elements to provide continuity for transferring all shear wall and collector forces through existing concrete elements.
- Provide temporary support and shoring of floor framing as necessary to facilitate the construction of new shear walls.
- Place new reinforced concrete shear walls on the centerline of existing framing lines with concrete of sufficient strength (minimum of 20 MPa; cylindrical strength), thickness (minimum of 30 cm), and reinforcement (15 cm maximum spacing each way for reinforcing bars) to resist in-plane and out-of-plane seismic loads. All reinforcing steel must be adequately chaired within forms and held in position during placement of concrete.
- Provide new reinforced concrete collectors below the existing floor framing along shear wall lines to deliver seismic loads to the new shear walls.
- Construct a cast-in-place reinforced concrete topping slab using concrete of sufficient thickness (80 mm minimum thickness), and reinforcement (15 cm maximum spacing each way for reinforcing bars) on the surface of all precast floor and roof planks. Lightweight concrete may be used for topping slabs to reduce the added weight. Provide epoxy dowels between the new topping slab and the precast planks. Provide reinforcing dowels between the new shear walls, collectors, and new topping slabs to transfer in-plane and out-of-plane seismic loads between the walls and the diaphragms.
- For architectural continuity at locations of new exterior shear walls, replicate the appearance of the adjacent precast wall panels using modern lightweight cold-formed steel studs and curtain wall construction.
- Replace roofing and floor finishes with new lightweight materials over the reinforced concrete topping slab.
- Replace demolished masonry partitions with modern lightweight cold-formed steel studs and gypsum wallboard. Construct new lightweight interior partitioning between classrooms and corridors, as needed.
- Clear, widen (as necessary), and protect (with appropriate architectural details) all anti-seismic joints between building wings.

D.2 Structural Narrative – Typology D-2 Typical Gymnasium Building

The structural narrative, plans, and typical details for conceptual seismic retrofit of Typology D-2 typical gymnasium buildings are the same as specified for Typology D-1 in Appendix C of these *Guidelines*.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.



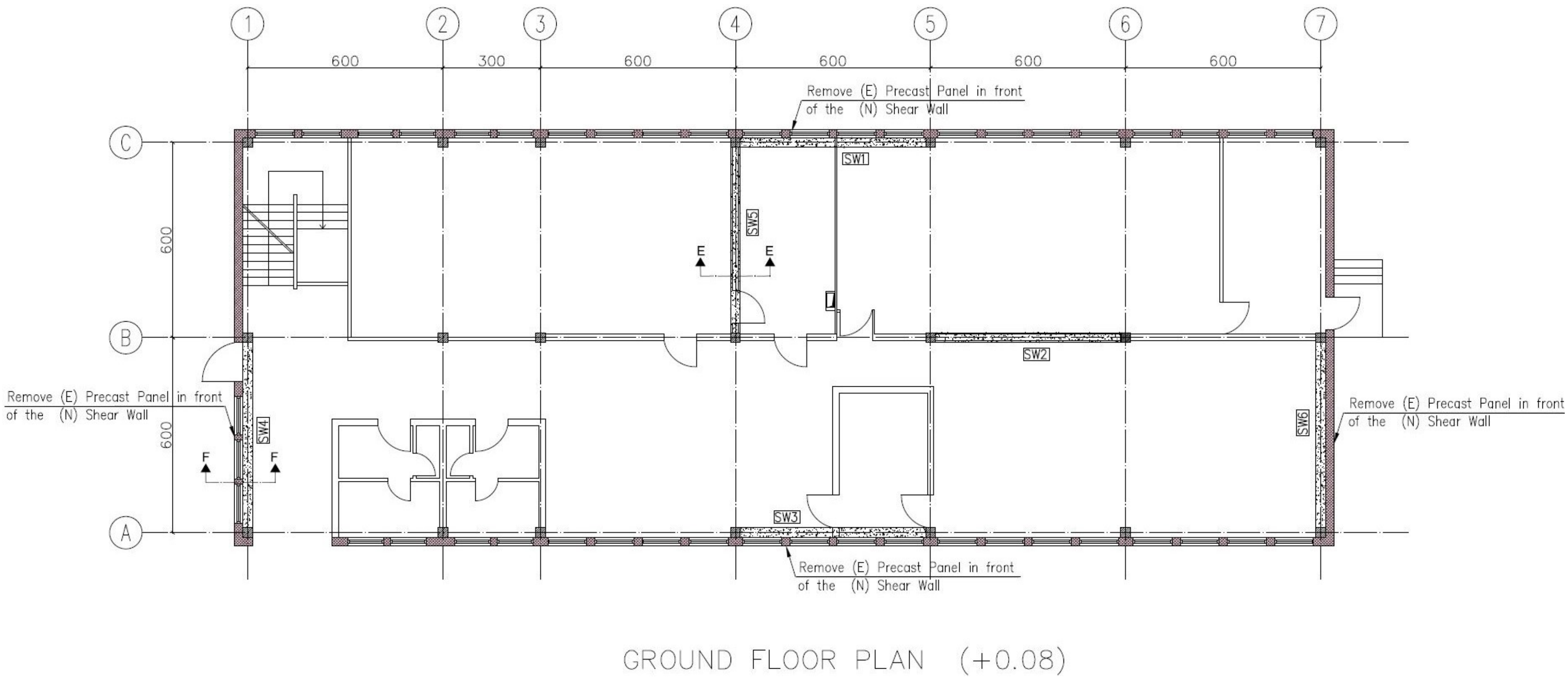
Preliminary, NOT for Construction

LEGEND	*MATERIAL PROPERTIES*	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure D-1 Typology D-2 typical classroom - foundation plan.

GENERAL NOTES:

1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.

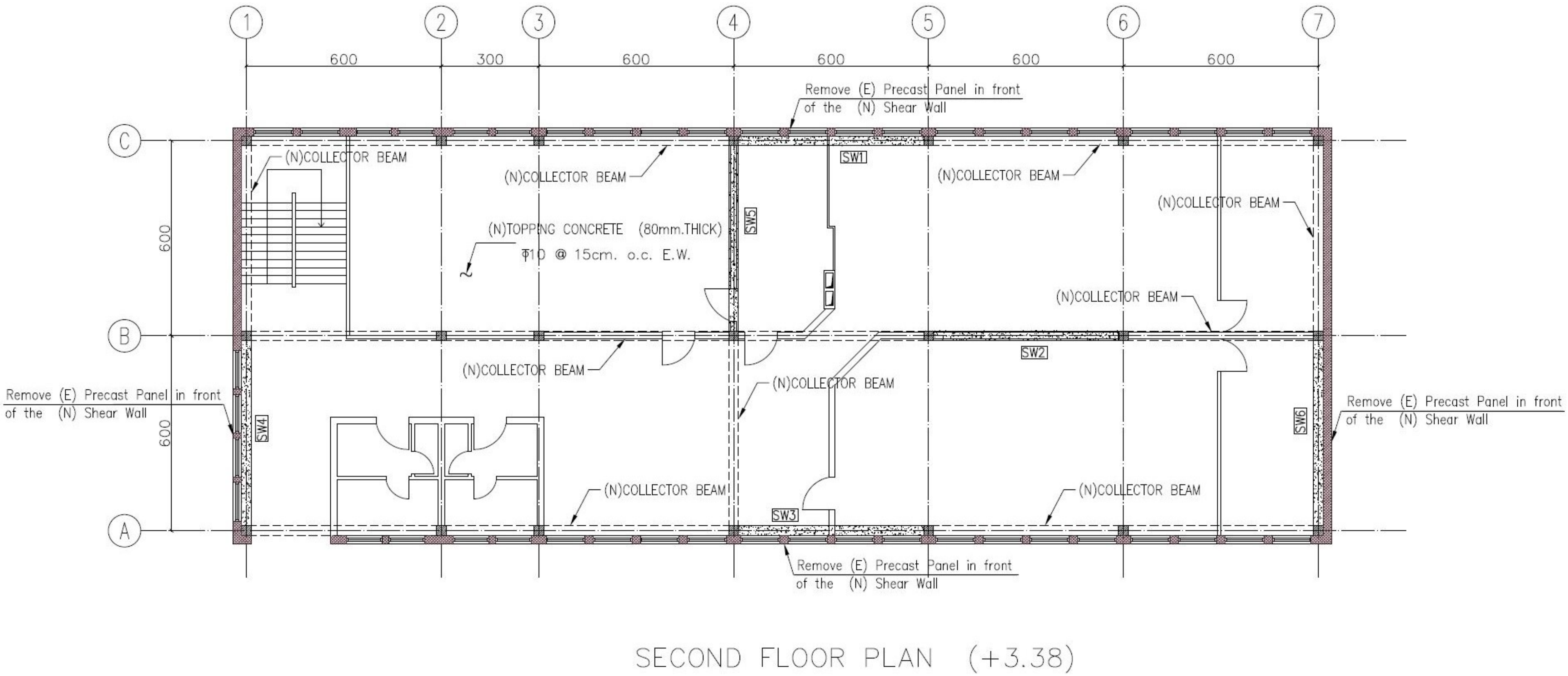


Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure D-2 Typology D-2 typical classroom - ground floor plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.

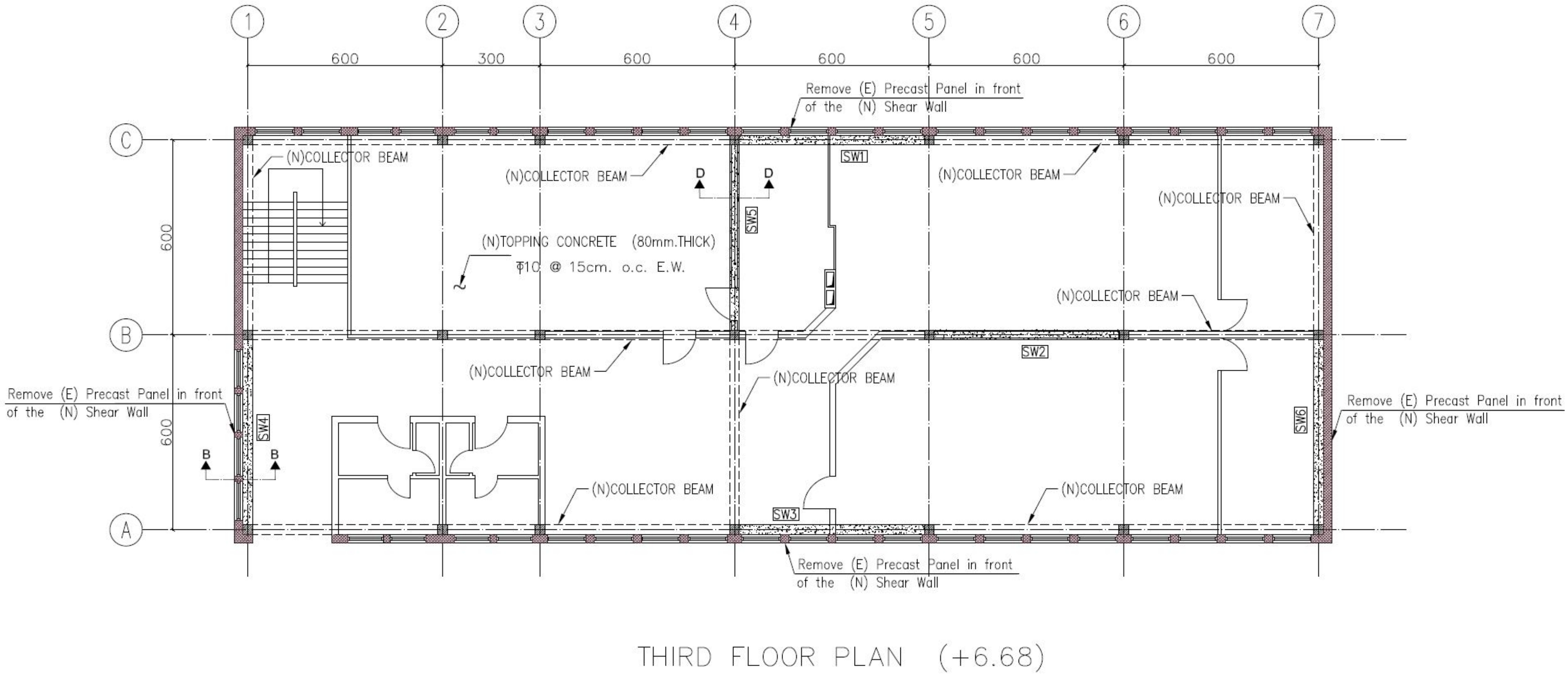


Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure D-3 Typology D-2 typical classroom - second floor plan.

GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.

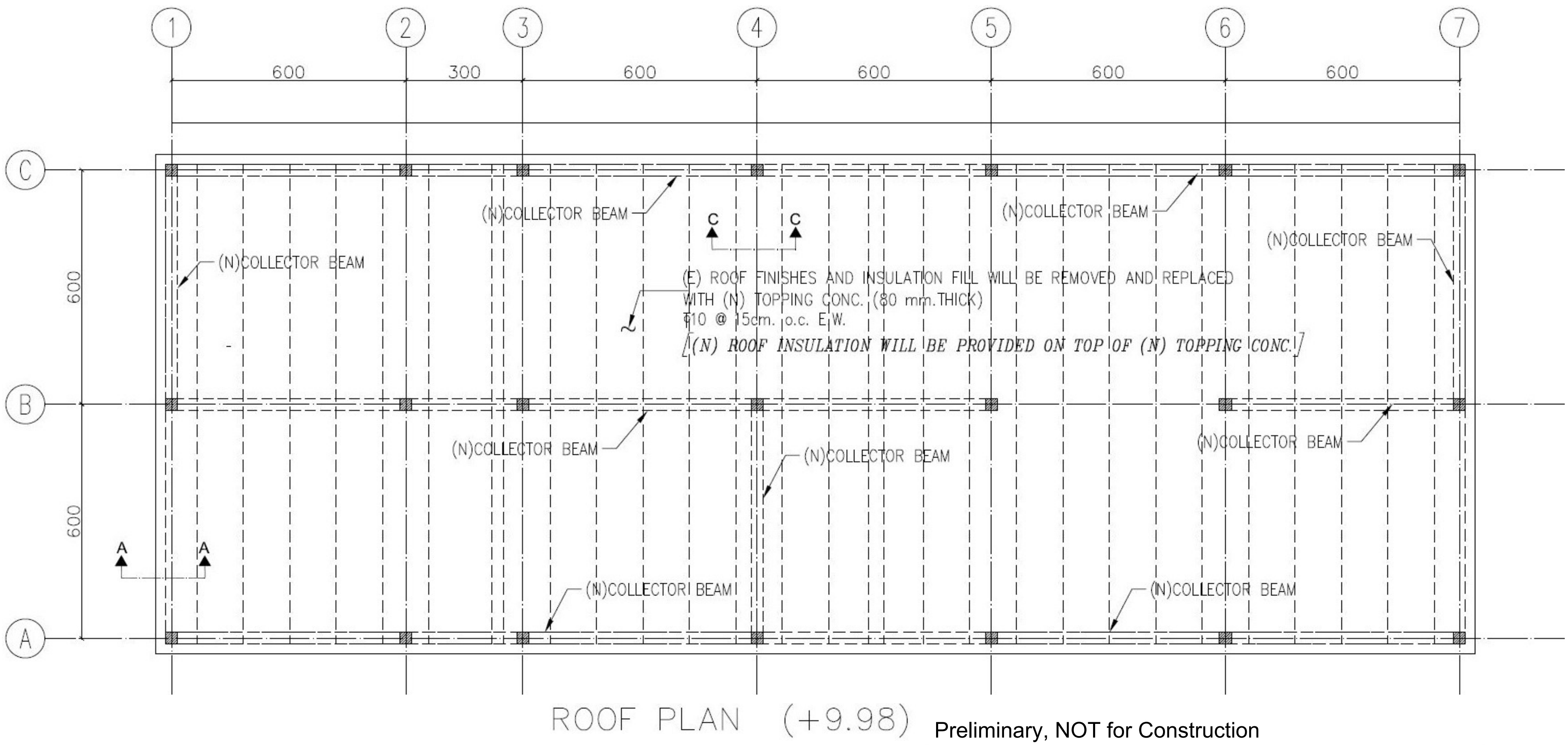


Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure D-4 Typology D-2 typical classroom - third floor plan.

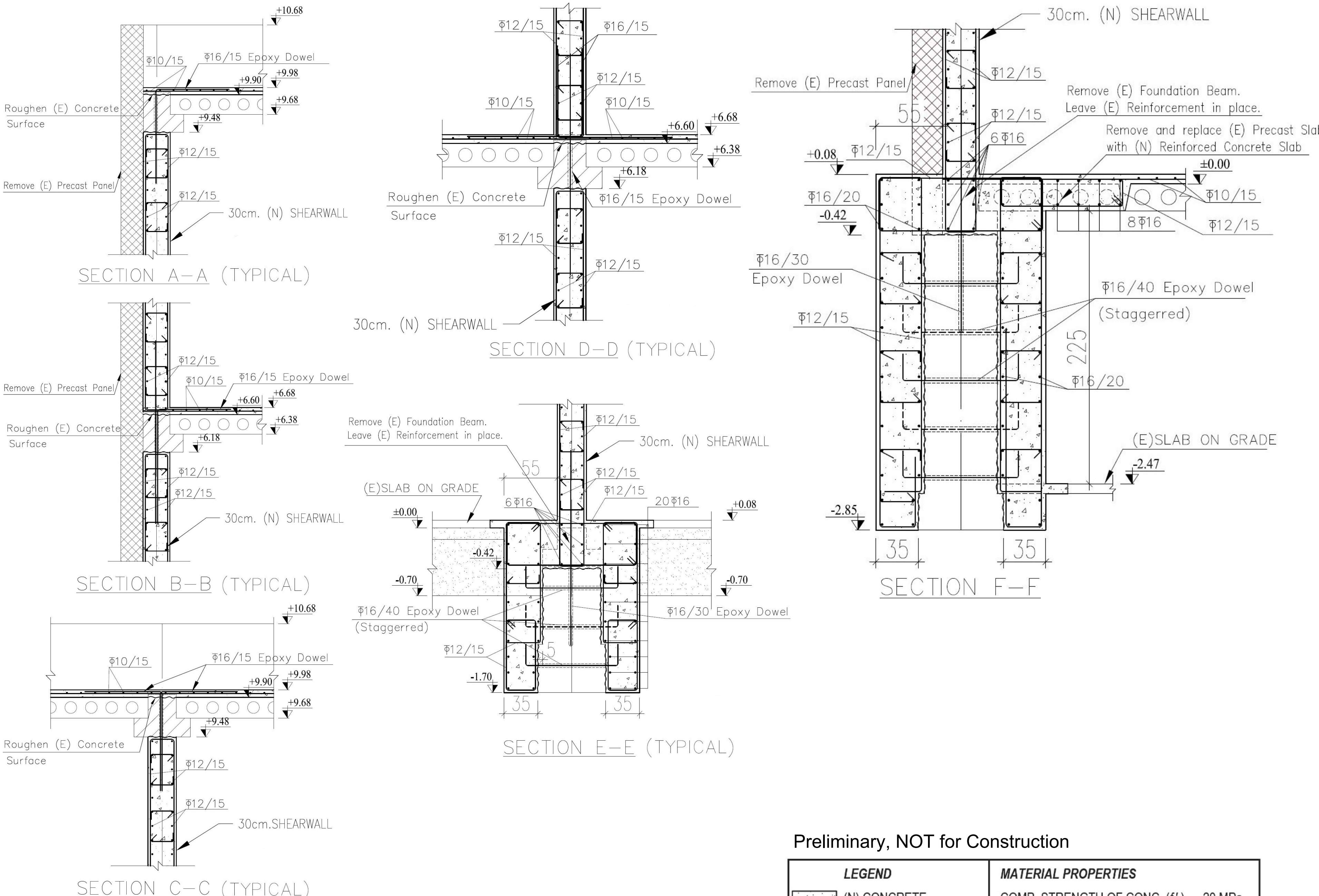
GENERAL NOTES:
1. ALL PEMZA PARTITION WALLS TO BE REMOVED AND REPLACED WITH LIGHT METAL STUDS AND GYPSUM WALLBOARD PARTITIONS.
2. (E) FLOOR FINISHES WILL BE REMOVED AND REPLACED WITH (N) REINFORCED TOPPING CONCRETE.
3. (E) ROOF FINISHES AND INSULATION FILL WILL BE REMOVED AND REPLACED WITH (N) TOPPING CONCRETE. (N) ROOF INSULATION WILL BE PROVIDED ON TOP OF (N) TOPPING CONCRETE.



Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

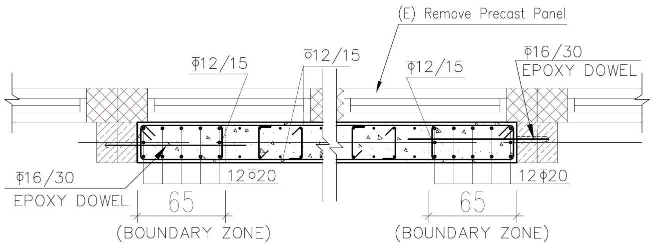
Figure D-5 Typology D-2 typical classroom - roof plan.



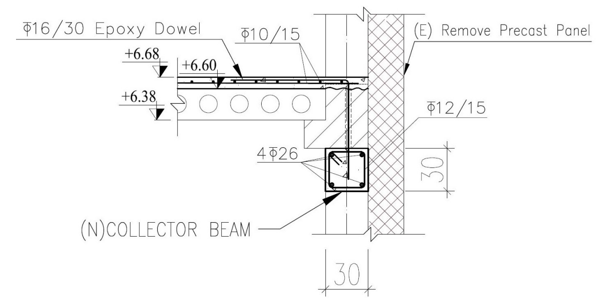
Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

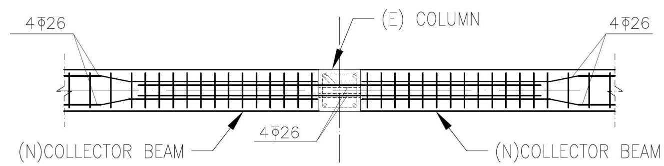
Figure D-6 Typology D-2 typical classroom - typical details.



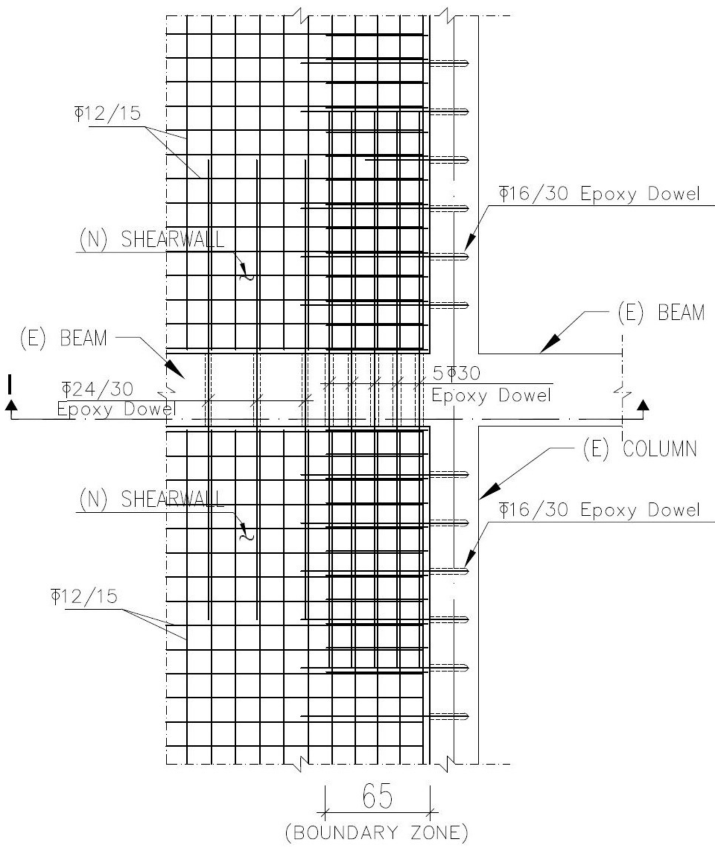
TYPICAL (N) SHEAR WALL SECTION



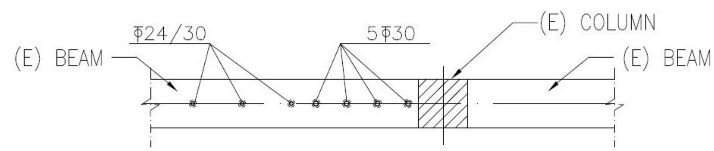
TYPICAL (N)COLLECTOR BEAM SECTION



TYPICAL COLLECTOR REINFORCEMENT CONTINUITY DETAIL



TYPICAL BOUNDARY ZONE & WEB REINFORCEMENT CONTINUITY DETAIL



I-I SECTION

NOTES:
Boundary and web reinforcement continuity will be provided with dowels @ centerline as shown above.

Preliminary, NOT for Construction

LEGEND	MATERIAL PROPERTIES	
(N) CONCRETE	COMP. STRENGTH OF CONC. (f'_c)	20 MPa
(E) CONCRETE	REINFORCING STEEL (f_y)	A500C
(E) PRECAST CLADDING		

Figure D-7 Typology D-2 typical classroom - typical details.

Appendix E

Conceptual Seismic Design for New School Buildings

This Appendix provides structural plans and typical details for conceptual seismic design of new modular school buildings. Conceptual plans and typical details provided in this appendix are summarized in Table E-1.

Table E-1 Conceptual Seismic Design Drawings for New School Buildings

Figure Number	*Figure Title*	*Page Number(s)*
E-1	Ground floor plan of UNDP prototypical new school. Dashed lines indicate locations of anti-seismic joints for structural separation between modules	E-2
E-2	Ground floor plan of UNDP prototypical new school. Heavy lines indicate proposed locations of concrete shear walls	E-3
E-3	Structural elevations at classroom modules of UNDP prototypical new school. Highlighted bays indicate conceptual locations of concrete shear walls	E-4
E-4	Structural elevations at gymnasium modules of UNDP prototypical new school. Highlighted bays indicate conceptual locations of concrete shear walls	E-5
E-5	Conceptual detail of reinforced concrete shear walls at intermediate floor or roof slabs	E-6
E-6	Conceptual detail of reinforced concrete shear walls at foundation	E-7
E-7	Conceptual plan detail of reinforced concrete shear walls at boundary columns	E-8
E-8	Conceptual detail of exterior closure walls	E-8

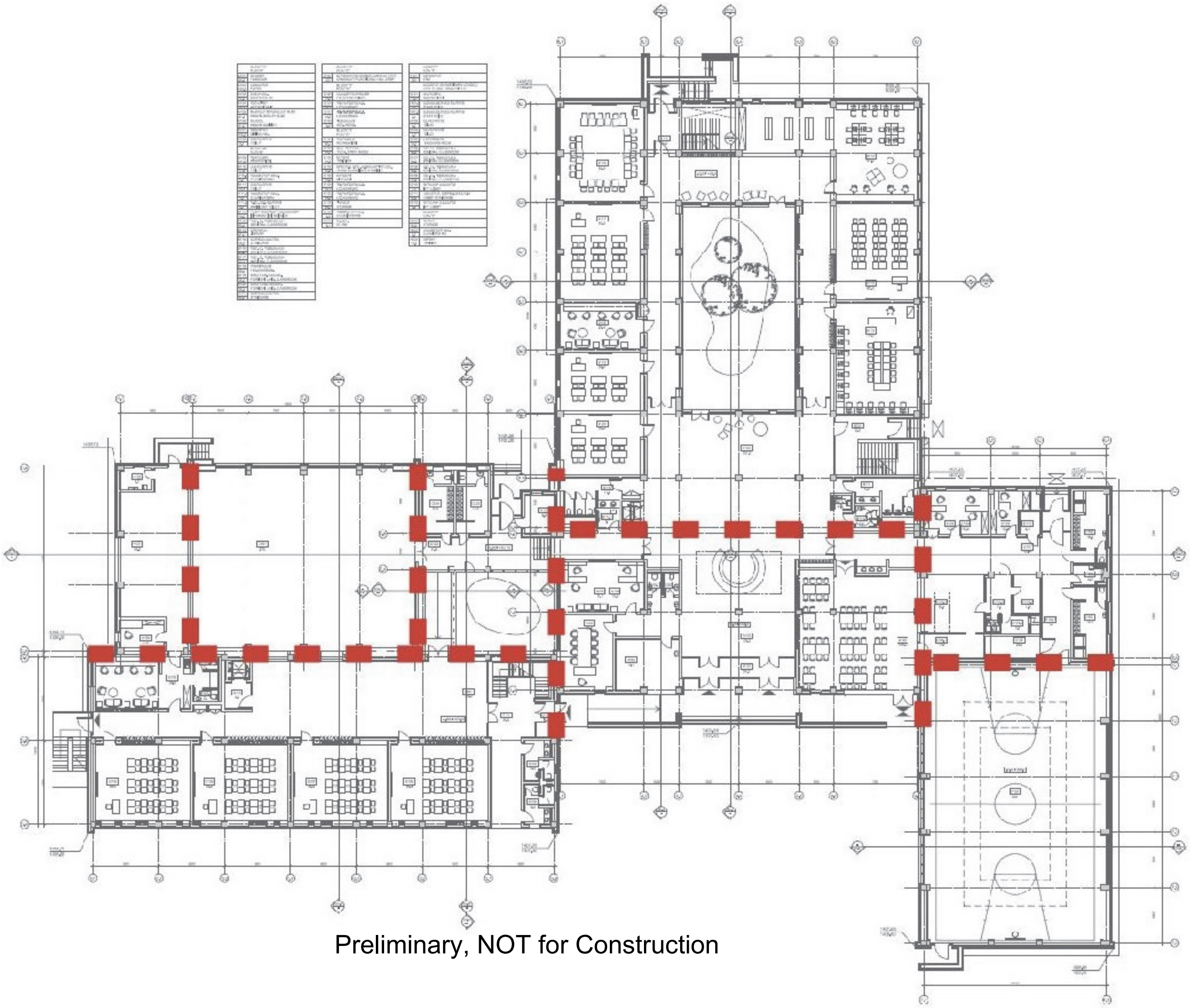


Figure E-1 Ground floor plan of UNDP prototypical new school. Dashed lines indicate locations of anti-seismic joints for structural separation between modules.

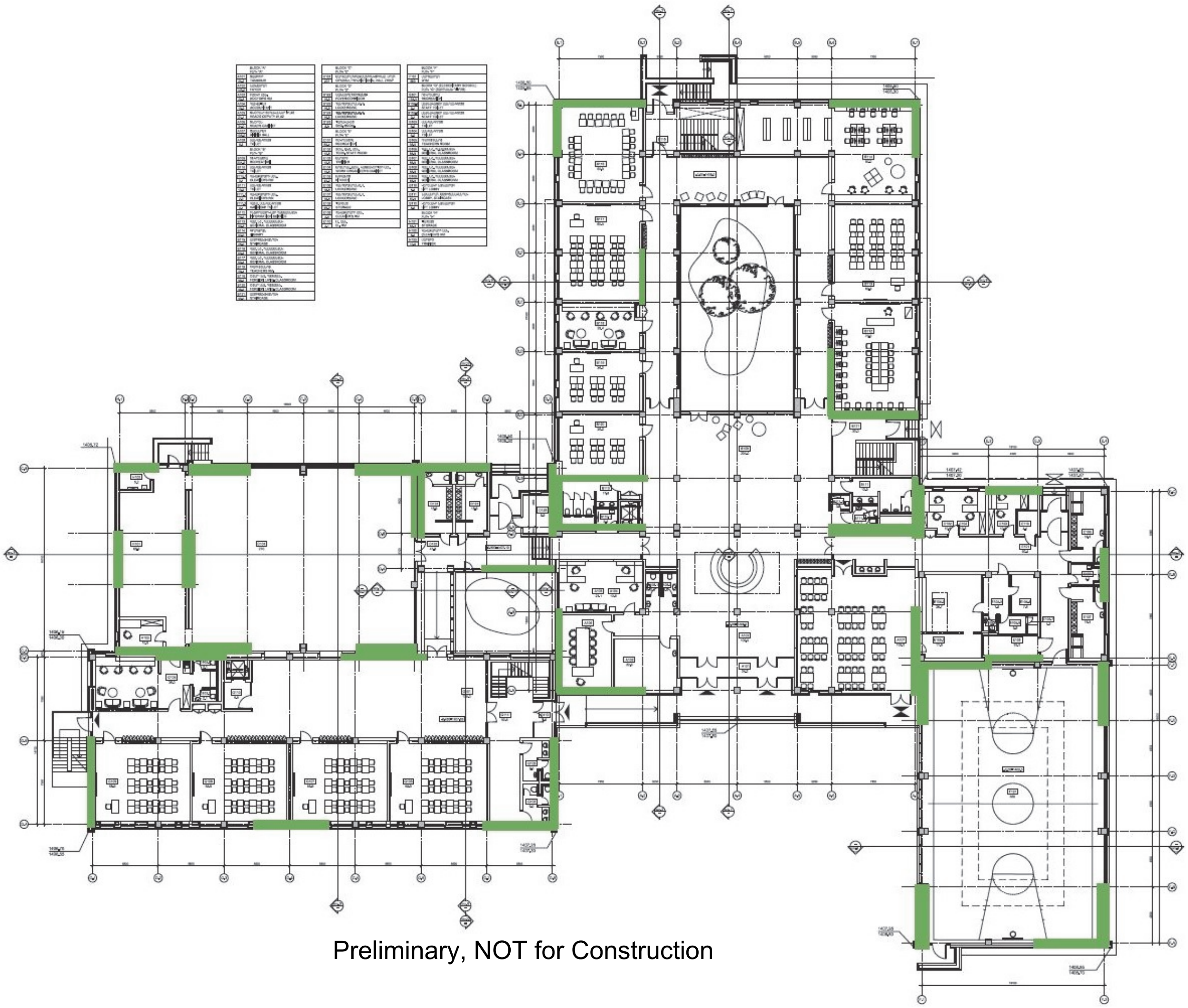


Figure E-2 Ground floor plan of UNDP prototypical new school. Heavy lines indicate conceptual locations of concrete shear walls.

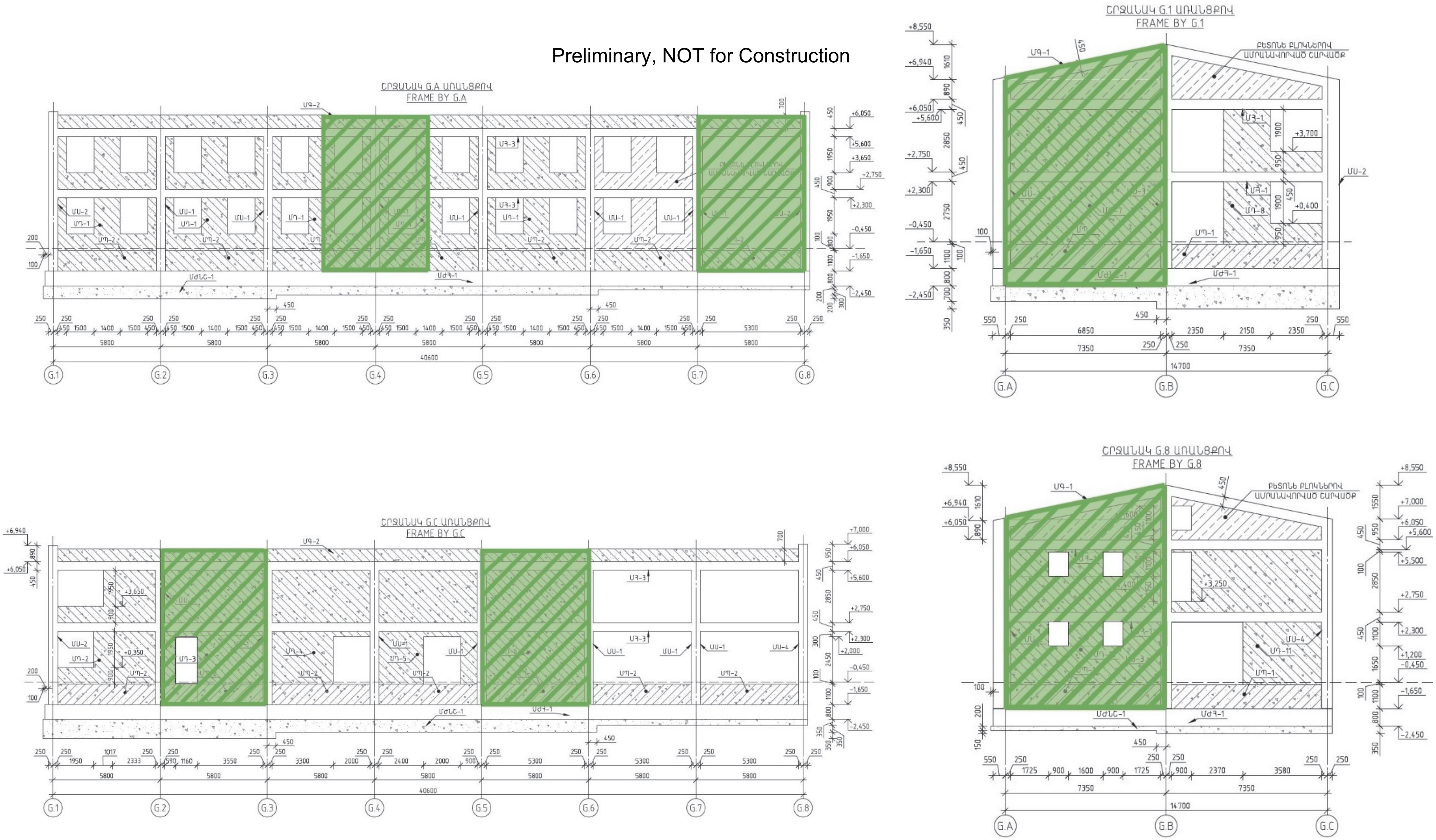


Figure E-3 Structural elevations at classroom modules of UNDP prototypical new school. Highlighted bays indicate conceptual locations of concrete shear walls.

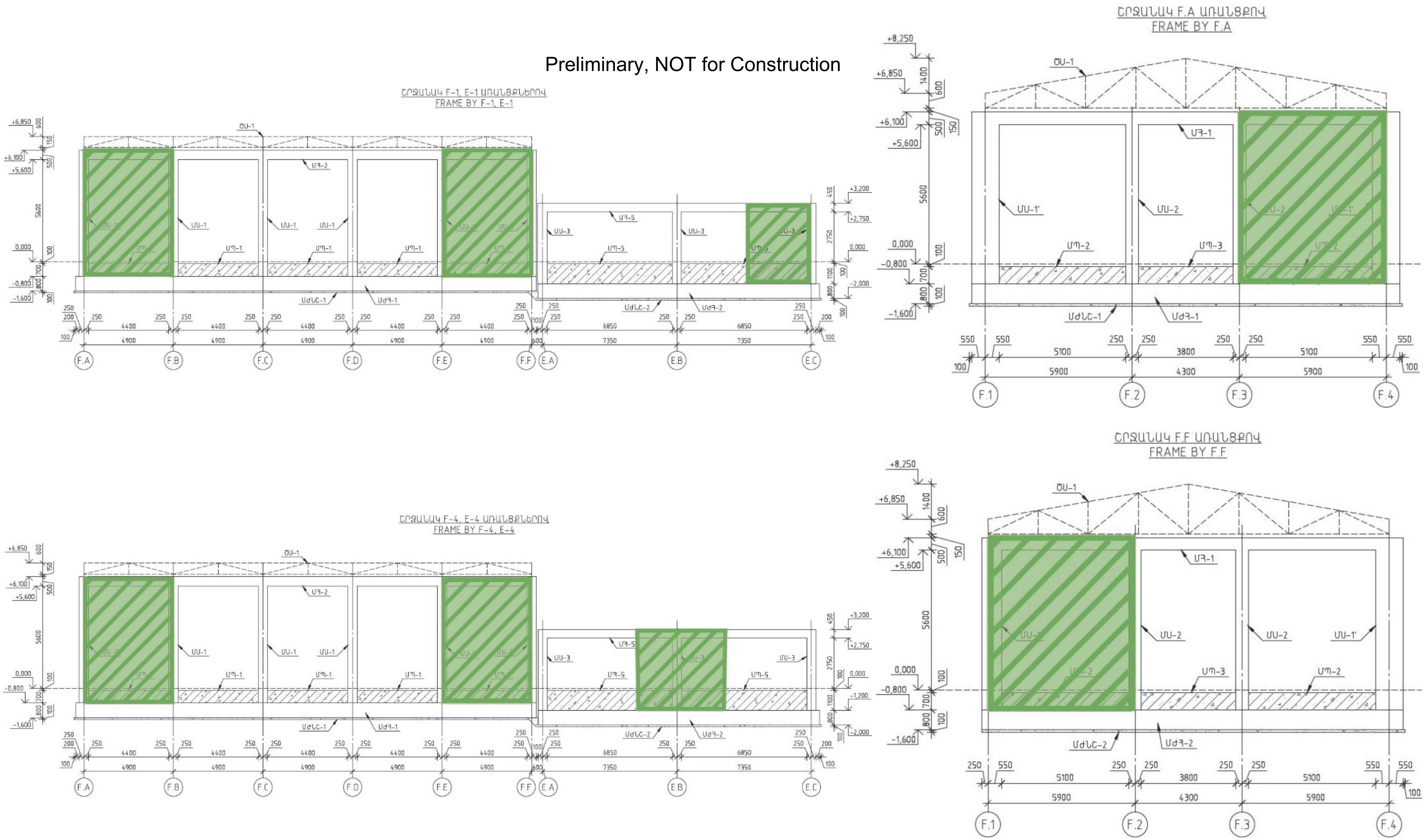


Figure E-4 Structural elevations at gymnasium modules of UNDP prototypical new school. Highlighted bays indicate conceptual locations of concrete shear walls.

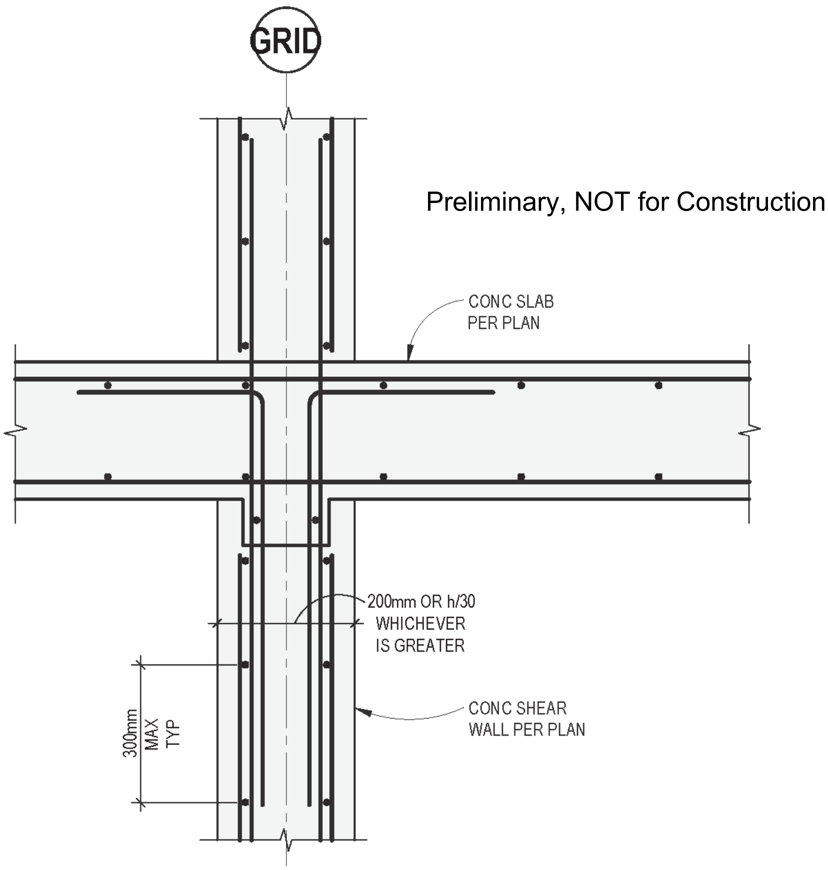


Figure E-5 Conceptual detail of reinforced concrete shear walls at intermediate floor or roof slabs (courtesy of MHP Structural Engineers).

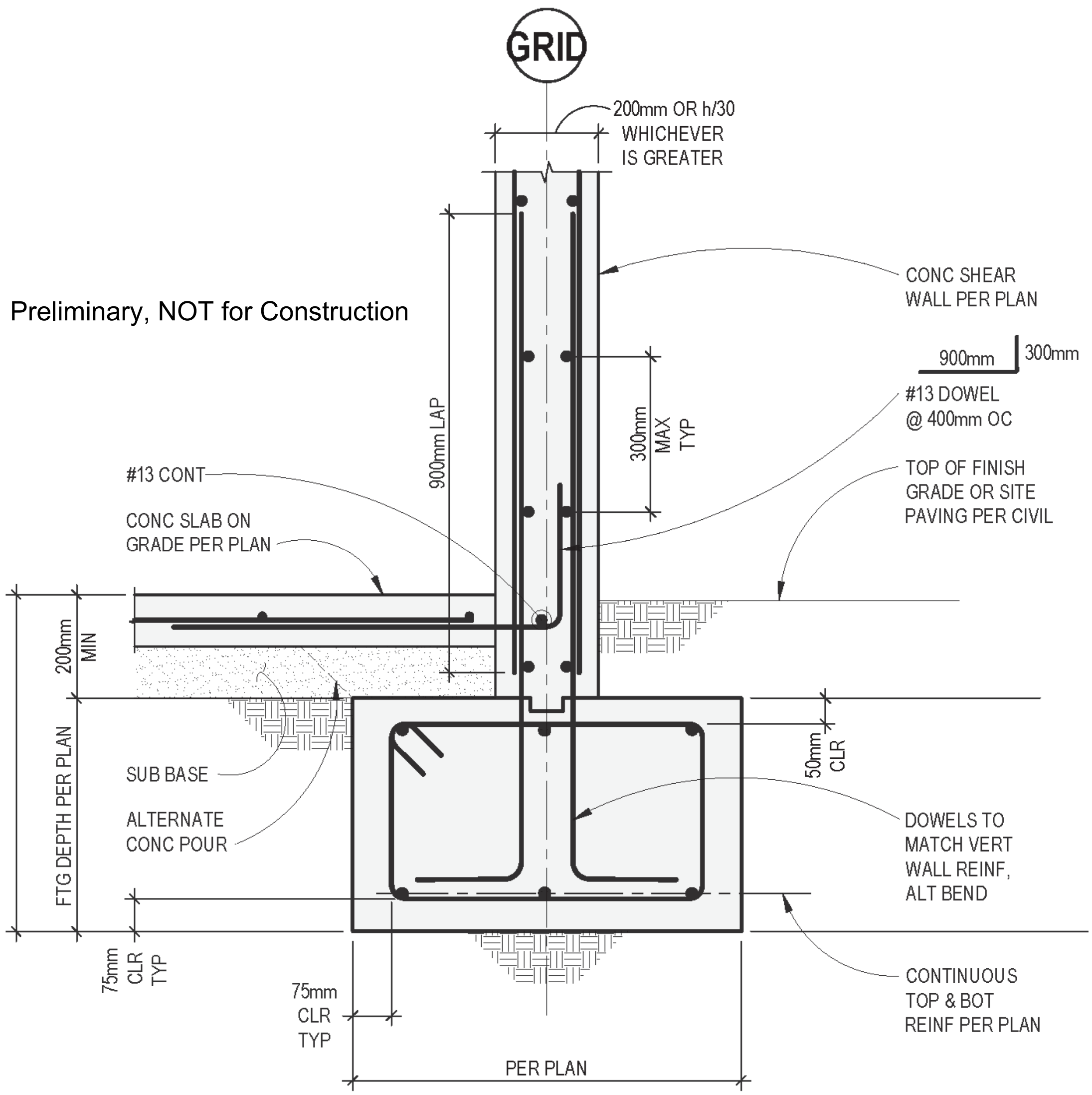


Figure E-6 Conceptual detail of reinforced concrete shear walls at foundation (courtesy of MHP Structural Engineers).

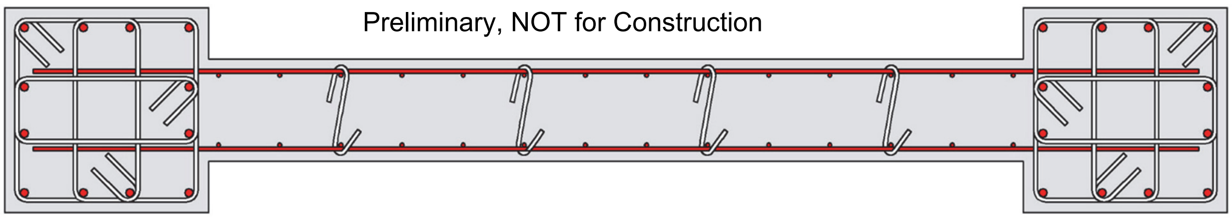


Figure E-7 Conceptual plan detail of reinforced concrete shear walls at boundary columns (courtesy of MHP Structural Engineers).

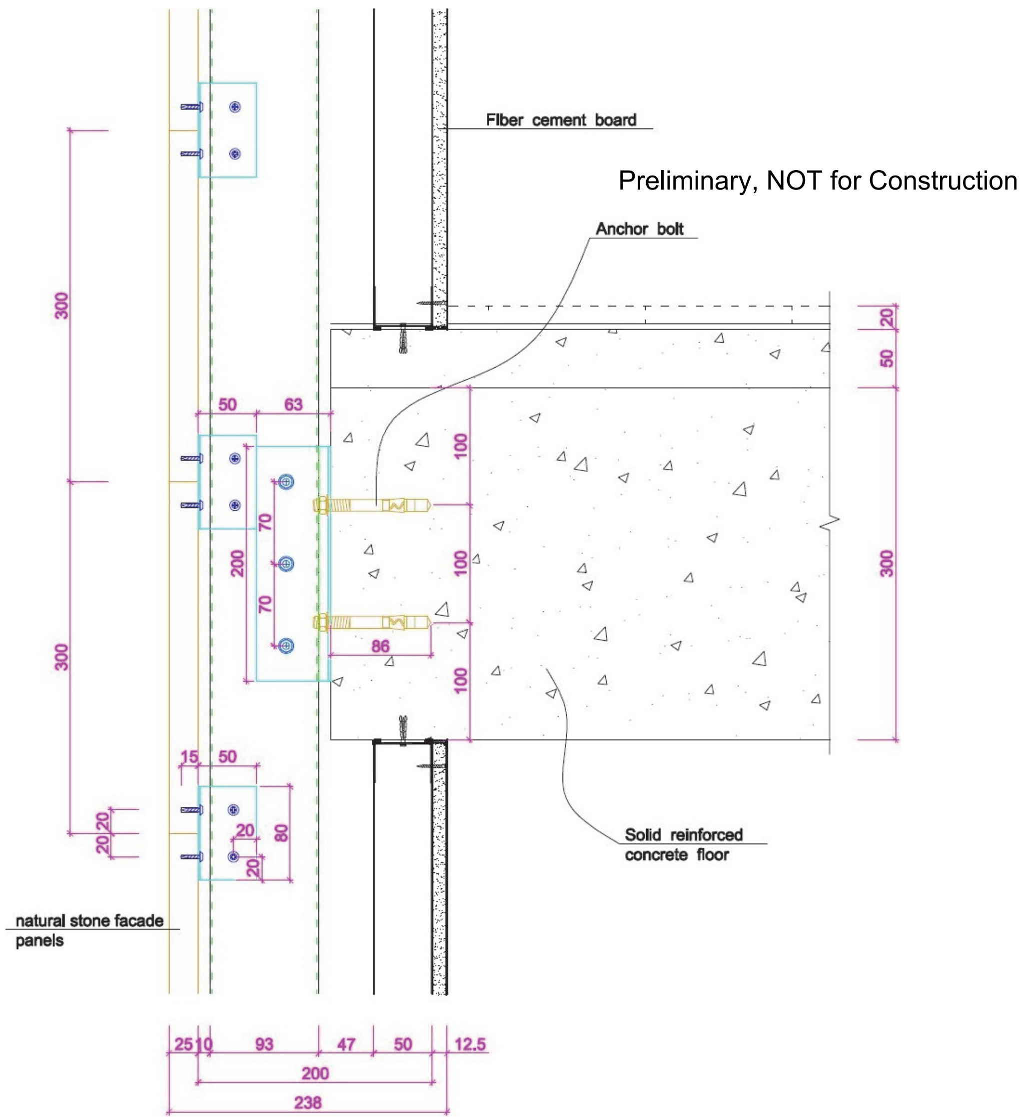


Figure E-8 Conceptual detail of exterior closure walls.

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