EARTHQUAKE HAZARD CENTRE NEWSLETTER

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Contents

Should reinforced concrete frames be banned?

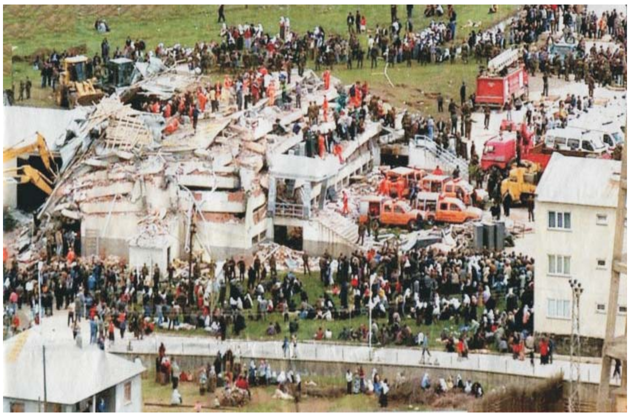
I've just been reading the preliminary reconnaissance reports of three damaging earthquakes that have occurred this year in developing countries - Colima Earthquake, Mexico, 21 January, Bingol Earthquake, Turkey, 1 May, and the Boumerdes Earthquake, Algeria, on 21 May. Just like most previous earthquake reports from developing countries they include many examples of how reinforced concrete frame buildings performed poorly. The reports noted a general lack of ductility in frames. Reasons included beam and column shear failure, beam-column joint caused by a lack of transverse reinforcement, poor reinforcement detailing and poor concrete. The most tragic incident of all occurred at a Turkish boarding school - 85 out of the 200 students in residence were killed.

As usual, soft-storey collapses were common - open ground floors with brick infill walls in higher storeys are almost guaranteed to fail. Buildings with these configurations are potentially dangerous. They are like cars with poor brakes. For speeds say under 30 km/h the brakes will stop the car, but at higher speeds they are ineffective and cars crash. Just as a car manufacturer wouldn't produce cars unsafe at moderate or even high speeds, so we building professionals should re-evaluate the use of RC frames.
RC frames weren't the only systems to perform poorly according to the reports. Some RC shear walls were also badly damaged. However, even though they had little horizontal shear reinforcement and exhibited wide X-patterned cracks, those buildings didn't collapse.

How can we make RC frames safe? First we must design and detail them so they possess the ductility that justifies such low levels of seismic load. This means using some type of Capacity Design approach. We must use good quality materials, including suitably strong concrete. We need to avoid soft storeys by physically separating infills from frame. If that is too difficult, we need to design soft-storeys for elastic response. That means increasing frame design loads by about a factor of 4.0. Correspondingly larger and stronger beams and columns will then survive a code level earthquake without collapse.

If we can't make these changes, then rather than using a system that almost every earthquake reminds us is flawed, we should cease using RC frames. They *should* be banned.

The Principles of Building Earthquake Resistance, on the next page, discusses the advantages and disadvantages of the three most common lateral load resisting systems for RC buildings.



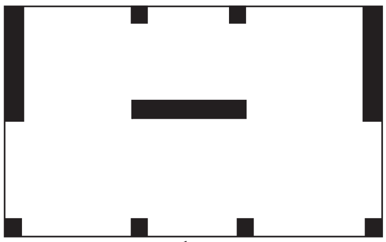
Collapsed Turkish Boarding School

Principles of Building Earthquake Resistance No. 26

Assessing different reinforced concrete structural options

What is the best structural system for a low to medium-rise R.C.. building?
The advantages and disadvantages for the three most popular options are listed below.
For more information refer to the previous Principles sections as noted.

R.C. Wall



Plan

Advantages:

- Design detailing not too onerous
- Infill walls can have openings as required
- No soft-storey even if infill walls only occur above ground floor
- Good record of earthquake performance

Disadvantages:

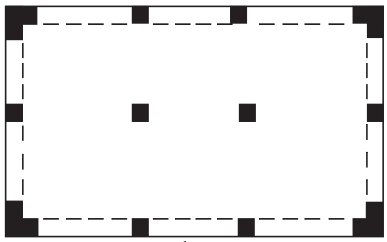
- Walls need to be integrated with space planning
- Few openings in lowest storey
- Foundations might need tensile strength to resist overturning moments
- Could be more expensive

References: Vol. 3, No. 2

Summary:
RC wall structures have a good performance record in past earthquakes. The best lateral load resisting system in reinforced concrete.

Overall Rating: *****

R.C. Frame (open)



Plan

Advantages:

- Least constraints on floor planning layouts
- Maximum transparency of exterior envelope
- Observed seismic performance average to poor unless 'capacity-designed'

Disadvantages:

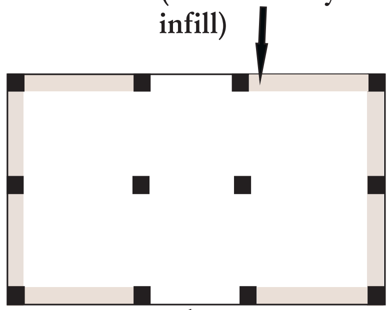
- Difficult to ensure good seismic performance as design, detailing and construction *all* need to be of a very high standard
- Infills need separation from frames yet need face load strength

References: Vol.2 No.4, Vol.3 No.3, Vol.4 No.2, Vol.5 No.4, Vol.6 No.4, Vol.7 No.1

Summary:
A very popular structural system but its performance in developing countries has often been poor. For improved reliability, modern methods of design and detailing are necessary.

Overall rating: ***

R.C. Frame (with masonry infill)



Plan

Advantages:

- Least volume of reinforcement and concrete
- Infills used for both space subdivision and as a structural element

Disadvantages:

- Need substantial lengths of walls to prevent infill shear failure
- Infill walls need to be continuous from foundations to roof
- Window-sized penetrations not possible in lower storeys

References: Vol.1 No.3, Vol.1 No.4

Summary:
Least reliable system unless well designed, detailed and constructed. Then good seismic performance is possible.

Overall rating: **

A Summary of "Craftsmen: A key for introducing earthquake resistant construction", by Jitendra K. Bothara

Introduction
Building structures in Nepal are mostly procured by the owner who employs a local skilled artisan to direct operations. Artesians play a pivotal role in the overall construction activity, and owners rely on them heavily for all types of advice. They provide overall technical and organizational support - even though none of them have formal training. According to conservative estimates more than 98 % of Nepalese houses are designed and constructed in this way. Further, introduction of earthquake resistant construction through engineers/ technicians is economically unaffordable, logistically impossible, and technically unfeasible in the foreseeable future. In this scenario, till these craftsmen are equipped with earthquake resistant technology, earthquake resistant construction will remain a mirage. This situation is probably applicable to most developing countries.

Present Scenario
The formal education system, the major means of disseminating knowledge, and its trainees often do not recognise local socio-culture, economics nor traditional skills and their potential for introducing seismic safety to the community at large. Since the process of dissemination of knowledge is considered complete once it reaches the engineer/technician level, craftsmen are still waiting to be recognised as stakeholders. Consequently, either no investment is made for training craftspeople/ masons or it exists in token form. Further, courses for craftsmen even if conducted, are too structured and of short duration. Most craftsmen are either illiterate or barely literate. Most come from informal system education and can not cope up with formal courses.

Further, on building sites where engineers are involved, either engineers and craftsmen work as rivals or craftsman work as subordinates rather than stakeholders. Opportunities for technology dissemination are lost.

Envisioned Strategy
Recognizing the socio-culture, local economics, and craftsmen's potential strength to implement earthquake resistant construction, and sustain it the, National Society for Earthquake Technology-Nepal (NSET-Nepal) took a pragmatic approach.

Retrofitting of existing school buildings or earthquake resistant construction of new school buildings, a component of the School Seismic Safety Program implemented by NSET-Nepal was envisioned as a means for awareness raising in general and technology transfer to craftsmen in particular. The program was community based and local craftsmen were encouraged to work on the projects. They received wages for work but contributed a portion of it to the school construction program.

The first goal of the program was to help them realize how important they are for implementation of seismic safety. Then they had to be convinced that the current system is not sustainable

Fig.1 A typical classroom training session

Informal, flexible course material was designed so the training could be very interactive. The course material covered construction materials and their behaviour and limitations, quality control issues, failure mechanism of different types of buildings, construction details, cost implications etc. so they can convince potential owners to adopt the new approaches.

The focus emphasised on-the-job training with some interactive classroom presentations (Fig. 1) of visual aids to convince them earthquakes destroy buildings. They learnt how buildings fail, where deficiencies are, and then their solutions. Rather than asking them to follow instructions blindly, they were helped to understand what they were doing, and "why", using simple examples and experiments so they could grasp the concepts. To convince them, small innovative destructive tests were conducted (Figs. 2, 3).

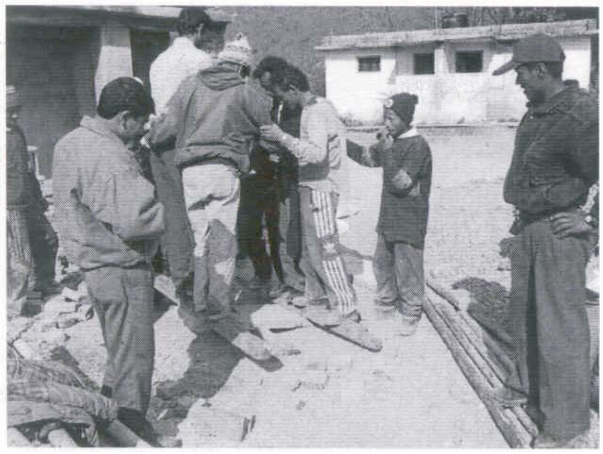


Fig. 2 Understanding the strength effect of steel reinforcing bar location in a slab.

Conclusion

It was observed that the craftsmen were quite receptive to technology in general and also eager to implement it. Even illiteracy is not a bar to understanding. We need to have confidence in them, understand their limitations and help them with the principles and practical aspects, not only engineering terms and understanding of drawings etc. We need to be more pragmatic.

Fig. 3 Understanding the effect pre-soaking bricks has on mortar and masonry strength

We also observed that the quality of construction of trained craftsmen was much better than that of their counterparts. After training they were able to convince owners to adopt earthquake resistant construction and replication of this work was instantly observed in the community (Fig. 4).

Finally we found that awareness raising (demand creation) and craftsmen training (supply) can be particularly effective if conducted simultaneously.

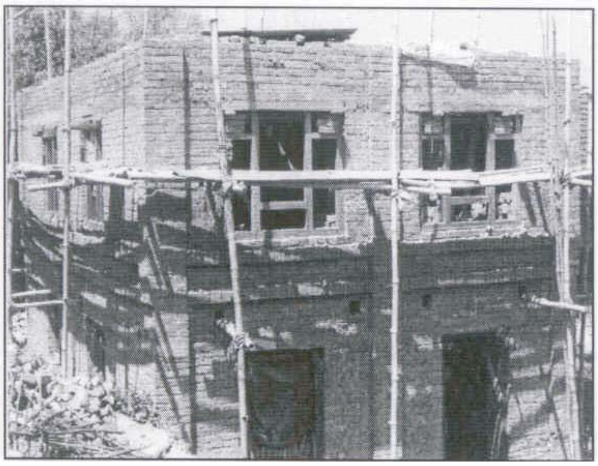


Fig. 4 Construction of an earthquake resistant house

(School Earthquake Safety Program and Craftsmen Training are NSET-Nepal's ongoing programs).

Jitendra K Bothara is a Nepalese structural engineer and currently a post-graduate student at the University of Canterbury, Christchurch, New Zealand

A summary of paper "Seismic retrofitting of mud/adobe houses", by Amit Kumar, Prof. Pratima Rani Bose and Col. AKS Parmar.

Introduction

In view of frequent seismic tremors at Pandhana tehsil, Khandwa district of Madhya Pradesh, India, the Disaster Management Institute, Bhopal conducted research for retrofitting non-engineered buildings, namely mud and brick buildings.

Features of existing construction

Traditional mud wall construction practiced in the Khandwa region is unique. Wall construction is partially load-bearing and partially framed (Fig.5)

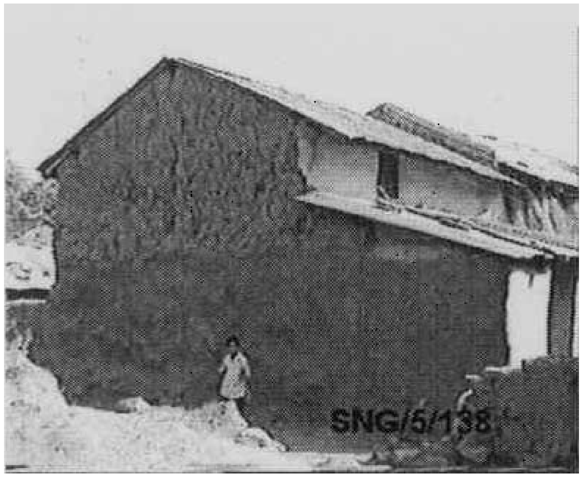


Fig. 5a Variation in mud wall houses: high mud wall

Fig. 5b Houses with timber framing

Generally, spread footing foundations are used for mud houses. The maximum depth of foundations is about 600mm. It is made up of random rubble masonry with mud mortar. The thickness of footing varies from 600 to 750mm. In many cases the foundation width continues above plinth level and gradually tapers down to wall thickness.

The mud wall is also used for partitions. Its thickness varies from 450 to 750mm but its soil quality is unsatisfactory. The soil behaviour is inconsistent in extreme weather. During the rainy season the soil swells extensively, and during the summer it shrinks causing cracks.

Columns are erected from the foundation. Timber columns of 200mm diameter are provided at intervals of 2 to 2.5 m longitudinally and transversely. Generally houses are of one storey with attics. Timber columns extend up to roof level. The column and beam joints are satisfactory but require further seismic fastening.

Roofing elements are made up of timber and covered with galvanised iron sheet, which is lightweight. Linkage between roofing elements are weak and require strengthening.

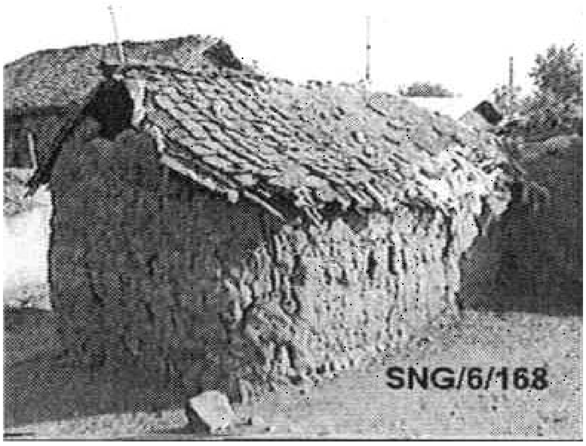


Fig. 5c Without framed walls

Retrofitting measures
The retrofitting technique has been developed on the basis of locally available resources, skill and construction materials. Mud buildings are highly vulnerable to seismic forces and perform erratically during ground shaking. The objective of strengthening is to integrate the building elements together so that the building can act as a single unit. Mud buildings are strengthened using bracing at weaker sections, and walls are joined with timber frames that are linked to roofing elements. The following steps are necessary when retrofitting mud buildings.

Removal of excess heavy roof covering i.e. tiles, timber planks, GI sheets, clay tiles etc.
Earthquake induced seismic forces are directly proportional to the mass of structural elements; the larger the mass, the larger the seismic forces to be resisted by the structure. The following procedure has been adopted:

- Remove clay tiles or GI roofing sheets carefully without altering the existing load path of the building. The roofing elements should not be repositioned unless all other reinforcing work at and above eaves level has been done.
- Place the wooden purlins and rafters (50-70mm dia.) at a spacing of 250mm centre to centre. The purlins are placed firmly with proper grooving in rafters. The rafters are fixed on a wooden band (eaves band) with steel straps.

Insertion of timber frame
The frame structure, having its own strength, acts perfectly well during ground shaking. Load bearing wall structures perform comparatively poorly, so we convert the load bearing wall to framed walls. In fact rural construction is partially framed anyway. Columns are to be inserted into the foundations. The eaves band positioned on the wall is to be properly fitted by making grooves in the inserted column.

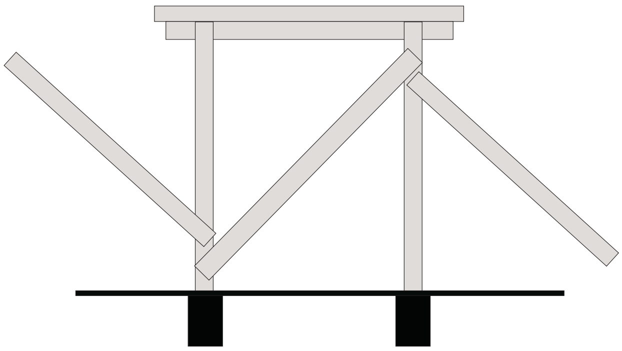
Strengthening of timber frame
Strengthening is done by bracing the frame and wooden members with diagonal and horizontal timber knee braces.

Installation of timber band
The top-most portion of the wall should be dismantled just below the eaves level and a timber band installed. The parapet wall should be reconstructed using the same material. The timber frame structure should be braced to prevent walls tilting inwards. The timber band is also to be provided at gable tops.

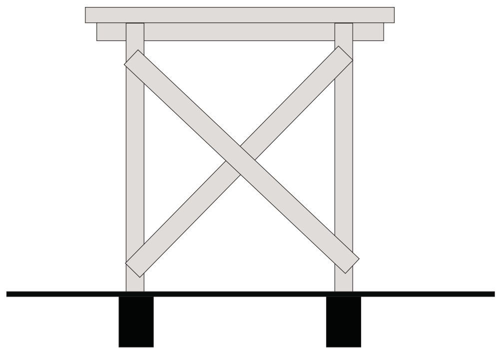
Knee bracing of a timber frame
Knee bracing should be introduced at the top of each timber post wherever possible to reduce lateral sway. Two braces are required at a corner post and four are required for inside posts in a multiple column-beam system. There are several possible types of knee bracing, depending on the availability of construction materials (steel or timber). Knee bracing length should be approximately 600mm. When steel bracing is employed, rolled steel angle of a minimum size 35x5mm should be used. For timber bracing, timber of 30x80mm cross-section may be used.

Diagonal bracing of timber frame
As an alternative to knee bracing, bracing of a timber frame by means of diagonal bracing elements is recommended. Bracing the house core area, particularly all the bedrooms, is the highest priority. Diagonal bracing should be provided firstly inside, and then on the outside of the house. Diagonal; bracing elements in adjacent spans should be positioned as illustrated in Fig. 6. A minimum of two braces should be installed in the adjacent spans. Alternatively, 'X' bracing should be installed within one frame span. Timber planks used on diagonal bracing should be at least 30x80mm cross-section.

Mud wall connection with frame
It is important to connect the timber frame to the mud walls. Grooves of 600mm are made on both sidewalls adjacent to the timber columns at vertical intervals of 600mm. Timber slats (100x75x75) are placed in the grooves and are fixed to the column joined together by bracing. Then the grooves are filled with prepared mud mortar.



Diagonal bracing

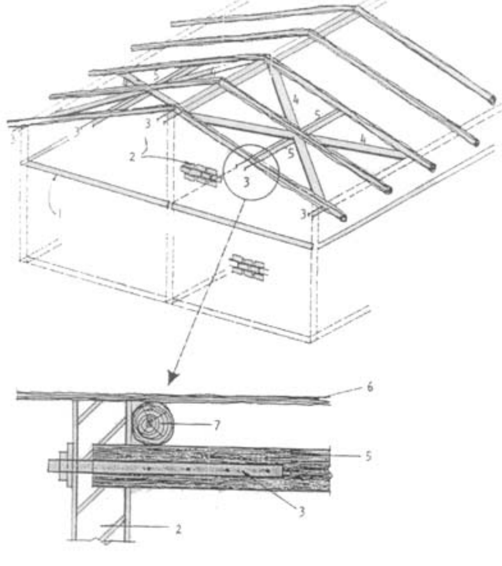


X Bracing

Fig. 6 Various diagonal bracing layouts

Roof strengthening
Welding or clamping suitable diagonal bracing members in the vertical as well as horizontal planes brace roof truss frames. Anchors to roof trusses from supporting walls should be improved and the roof thrust on walls should be eliminated. Fig. 7 illustrates one method. Where the roof or floor consists of prefabricated units like rectangular, T or channel units, or wooden poles and joists carrying brick tiles, integration of such units is necessary. Timber elements could be connected to diagonal planks nailed to them and spiked to a perimeter wooden frame at the ends.

Waterproofing of mud wall
A major problem with mud is the threat of water. Mud walls not only get eroded, but on account of wetting become soft and loose their compressive strength. Mud walls are therefore invariably subject to damage due to rain and seepage. Non-erodable mud (NEM), plastered onto mud walls, is prepared by mixing in bitumen cutback. NEM plaster has been adopted very successfully.



1. Existing floor, 2. Existing gable wall, 3. Steel strips bolted to new ties, 4. New planks, diagonal bracing, 5. New planks, ties, 6. Roof covering, 7. Existing roof rafters

Fig. 7 Roof bracing and connection to gable wall

GI sheet or tile roofing
Suitable connections between roof structures and the walls is absent in most cases. A GI sheet, when improperly supported directly on the roof band, requires cutting the band. Cuts are also required to embed the rafters or purlins. However, such cuts are not permitted. Instead one or two courses of burnt brick masonry should be provided to hold the GI sheet roofing. On the front side, bolts can be embedded in the burnt brick masonry over the band and the walls. Alternatively, on the front side a purlin can be used along the inner or outside of the band and J bolts used through this purlin and flat on top to hold the GI sheets in place.

References:

- IS:1893:1984: Indian standard criteria for earthquake resistant design of structures
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- IS:13920:1993: Indian standard code of practice for ductile detailing of RC structures subjected to seismic forces

- IS:13935:1993: Indian standard guidelines for repair and seismic strengthening of buildings
- Guidelines for earthquake resistant non-engineered construction, October 1986
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Conference and announcement

Asia Conference on Earthquake Engineering (ACEE 2004 Manila), 5-6 March 2004 Manila Pavilion, Philippines, Organised by Association of Structural Engineers of the Philippines, Inc. (ASEP)

Conference Theme: "Science, Engineering, Rehabilitation and Response"

The Asia Conference on Earthquake Engineering (ACEE 2004) is organized by the Association of Structural Engineers of the Philippines, Inc. (ASEP) in cooperation with the various private and government institutions. The conference aims to provide a venue for leading researchers and practitioners coming from "earthquake countries" in the Asian region, both from highly seismic zones and moderately seismic zones, to share experiences in addressing the need to reduce the devastating effects of earthquakes through dialogue, cooperation and networking.

Themes:

- Geology and Seismology
- Geotechnical Engineering
- Design for Earthquakes
- Information and Computing Technology
- Lessons from Past Earthquakes
- Performance of Structures
- Seismic Diagnosis and Strengthening
- Lifeline Engineering and Management
- Disaster Preparedness, Mitigation and Management

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The Dubai International Award for Best Practices (UN-Habitat)

The Best Practices and Local Leadership Programme is able to raise awareness of some of the most pressing social, economic and environmental challenges of an urbanizing world. The Award also calls attention to the potential solutions to these same challenges. Every two years, 10 Best Practices are recognized and awarded with a US$ 30,000 prize, a trophy and a commemorative certificate. The next Dubai International Award will be presented in the year 2004.

Sharing Lessons Learned from Best Practices
The Dubai International Award plays a crucial incentive role in the identification of Best Practices from around the world. Over 1,600 Good and Best Practices from 140 countries have been compiled on the Habitat Best Practices database. The 2003 edition of this database is currently available on the Internet at: http://www.bestpractices.org

To access the database use the password "gen26".

Through its global network of partners, Best Practices are analyzed with a view to extracting lessons that others can learn from and incorporate into their own work. From this material, the BLP and its partners produce casebooks, engage in the transfer of practical knowledge, experience and expertise, and develop tools to facilitate learning and capacity building. These tools are in continuous development and are available on the Internet at: www.sustainabledevelopment.org/blp

The Dubai International Awards for Best Practices in Improving the Living Environment is open and will run up to 31 March 2004. Submissions are welcome from all quarters and all documented projects and initiatives meeting the Award criteria will be considered. The submission guidelines for the award are available on http://www.sustainabledevelopment.org/blp/awards / http://www.bestpractices.org/bp2004

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries
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