THE SEISMIC GAP:ISSUES OF SEISMIC DESIGN IN POST DISASTER RECONSTRUCTION

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Abstract

Recent experiences in post earthquake reconstruction have under lined the need to address three specific areas of “unintentional” seismic construction, which are:

- The impact of infill (usually brick) walls on reinforced concrete frames
- The seismic bracing effect of stairs that are not isolated from the building
- “Soft Storey” where there is a vertical change (usually to provide an open ground floor area) of building stiffness.

These can and do result in sudden and unexpected failure of buildings in seismic events. Moreover, they are not usually covered in codes, their causal effect in a building’s collapse can be masked by other factors and they are often an accepted part of construction prior to the earthquake disaster. Hence, they are readily repeated by aid agencies in any subsequent reconstruction even when there is seemingly engineering input. Fortunately, they can be corrected in both a practical and cost effective manner if they are addressed early in the design and construction stages. But unfortunately, they are not and examples will be taken from the post disaster reconstruction in Pakistan (following the 2005 Kashmir Earthquake), in Yogyakarta (following the 2006 Java Earthquake) and Banda Aceh (following the 2004 Asian Tsunami) to underline their persistence.

The “unintentional” tag highlights that these details are often shown on the architectural drawings instead of the structural engineering drawings or are modified during construction and their effect on the structure is perhaps not identified as much as it should or could be?

Keywords: Seismic Design, Earthquake Risk, Structural Design.

Background in Seismic Theory

Seismic design has the following 3 objectives:

(a) For small but frequent seismic events, building may suffer repairable damage to non-load bearing parts of the buildings. Main load carrying members should not suffer any damage.
(b) For moderate but occasional seismic events, these main load-carrying members may suffer repairable damage and non-load bearing parts may need to be replaced.
(c) Finally, for strong but infrequent seismic events main members could be expected to suffer irreparable damage, but the building should not collapse.

The distinction between these 3 objectives is probabilistically based using the Poisson's equation:

$$p= 1-e^{-L/T}$$

p= probability of occurrence
T= return period of the earthquake usually taken as 500 years for (c)
L= the life of a building usually taken as 50 years.

And consequently for objective (c) using the above values for T and L would mean a 10% probably of it being exceeded over a 50-year period. This is the usual minimum benchmark adopted in seismic design codes.

However, some buildings such as hospitals and fire stations must be immediate functioning after a seismic event and the return period for this class of buildings is increased from 500 to 1000 years and in some cases to 2,500 years.

When an earthquake does occur it imparts accelerations to the ground, which are then "re-interpreted" by the building. Consequently, buildings at the same site will respond differently to the same seismic event depending on the period of the building, the structural material used and the structural system adopted.

The period of a building is the time it takes for the building to move away and return to its original position when subjected to seismic loads. Figure 1 below shows the relationship between this period and the spectral acceleration coefficient. This coefficient when multiplied by the expected peak ground acceleration for a specific site gives the seismic acceleration that would occur at the site.

The Indian Code has a useful approximation for the period of a building, which is as follows:

$$T = 0.09 \times h/\sqrt{d}$$

T= natural period of vibration in seconds
h = building height
d = building width in the direction of the earthquake shaking being considered

This equation indicates a period of around 0.1 seconds for each storey and hence, it is only above 5 stories (0.5 seconds) that there is any reduction of the seismic load due to the period of the building. Expected peak ground accelerations (pga) vary and in India for example go from 0.10g for zone 2 up to 0.36g for zone 5 (based on IS1893: 2002). Thus, when multiplied by the spectral coefficient from figure 1 would mean a seismic acceleration of 0.25g to 0.90g. These are significant forces and without a ductile design approach would not be practically achievable in many/most buildings. Ductility is the ability of a building's seismic resisting system to dissipate seismic energy generated by the seismic accelerations noted above but still meets the stated 3 seismic objectives mentioned earlier. Different materials and different structural systems have different ductility capacities. A higher ductility capacity means lower seismic design forces. No (or minimal) ductility means that the building has to be designed elastically (thus minimal energy dissipation) and hence take the full 0.25g to 0.90g accelerations and the resultant forces that this produces. These factors of material and structural system are commonly combined (as it is for the Indian code) into "R" factors, which are tabulated in most seismic codes.

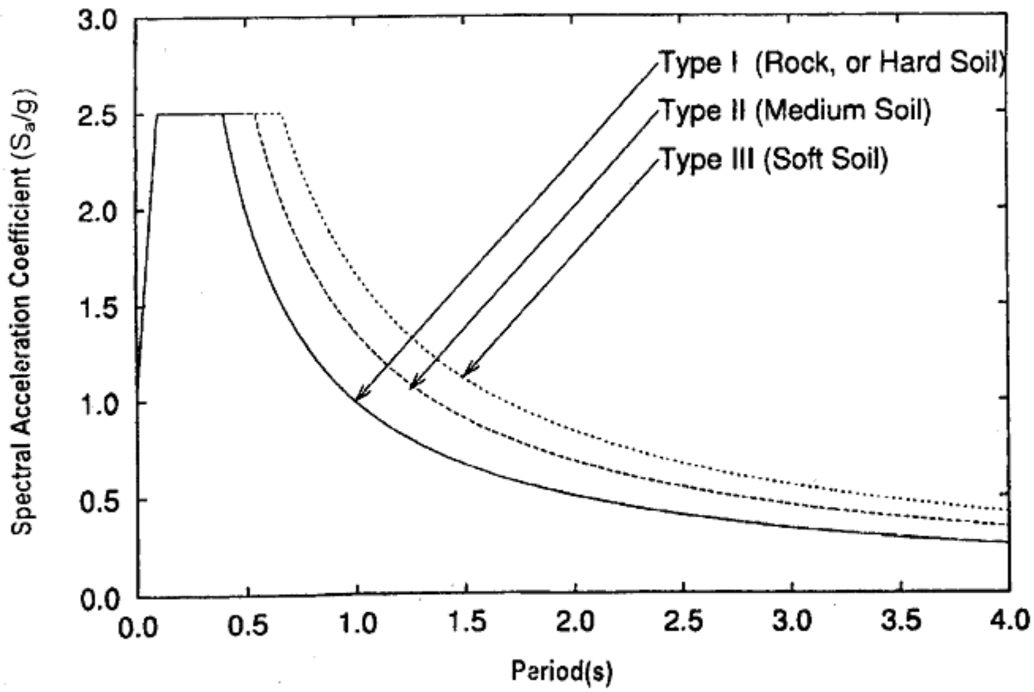


Fig. 1. The Relationship of a Buildings Period and its Seismic Loading

Finally, the seismic load is introduced into a building by the masses located inside. F=ma means that forces F will be generated by the seismic accelerations of 0.25g to 0.90g acting on these masses distributed throughout the building. To resist these forces a building requires both strength and stiffness. Strength is inherent in the materials provided and is intuitively understood whereas the role of stiffness is not. Stiffness is inversely proportional to deflection, the less a structural element deflects the stiffer it is and the more load it carries relative to other less stiff structural elements. Hence, seismic forces generated throughout a building will take the (relative) stiffest path to the foundations and hence back to the ground where the forces originated. This critical concept is at the core of the seismic design.

What then are the impacts of the three specific areas of seismic construction? These are defined and their impacts highlighted with photographs in table 1 below. They will be discussed in more detail later in the paper.

Table 1. The impacts of the 3 Specific Areas of "Unintentional" Seismic Construction

The 3 areas of seismic construction	Their construction typology	Their impact in a seismic event
Infill brick walls	Brick infill walls are built into reinforced concrete frames typically as cladding. The brick is laid hard against the beams and columns of the frame. The reinforced concrete frame was the intended structural system but is now altered by the inclusion of the infill. (Photo note: the impact of the infill walls on the damaged columns).	
Bracing effect of stairs	This occurs where structural elements such as flights of stairs are not disconnected or isolated from the building. Consequently, the stairs take seismic loads they have not been designed for and which can radically change the buildings response. Again, the reinforced concrete frame was the intended structural system (Photo note: the stair was bracing the house till it snapped in the middle)	
Soft storey	This is where structurally stiff elements such as walls and infill panels are prematurely stopped before reaching the ground. This often occurs at the ground floor level where the need for more open space results in stopping walls at the first floor level. (Photo note: the sign in the photograph was originally at the first floor of the building not the ground floor as shown. The ground floor has collapsed under the building).	

Research Method

The three specific areas of seismic construction presented in this paper were not so much selected but were observed by the author as being “evident”, “noticeable” and “apparent” in several post disaster earthquake situations that he was involved in.

They are important firstly because they severely impact on the seismic capacity of presumably new fully seismically designed buildings but also because they are an indication that perhaps something is not correct with the design and construction associated with the building (or buildings). They can be clearly and easily identified in buildings and they do not need significant checking of calculations, designs and interviews to be confirmed. Moreover, their presence suggests that “build back better” is not effectively happening but also questions the seismic grounding of the development program. But perhaps more importantly (if all that that was not enough), it does question the effective use of funding which quickly becomes an issue that implementing organizations often/always do not want to be open for public or even internal review. Consequently, many involved in the post disaster reconstruction are typically required to sign or have in their employment contracts non disclosure clauses and hence the reporting of any seismic issues remains informal and unreported even when agencies move to address such issues. And this is perhaps the final motivation for this paper that the various ‘lessons learnt” were not addressing and could not address the fundamental issues witnessed in seismic disaster reconstruction. But given this context, what would be a suitable or even achievable research methodology?

The methodology adopted has two parts. The first part sets out to show that these three specific areas of “unintentional” seismic construction have significant life safety and potentially building collapse implications. This will be in part based on the Indian Seismic Code given it’s relevance to brick buildings; it is one of the few codes that has an “R” value for load bearing brick walls.

The second part of the methodology then sets out to get an impression of the extent of these issues in post-disaster reconstruction by using photographic evidence taken off the web and from the author’s own photographs.

Research Questions or Research Hypothesis

- Do these three specific areas of seismic construction represent major seismic hazards?
- Is their presence “common place” in reconstruction?
- Does their presence suggest that the principles of good seismic design in post-disaster reconstruction are not being applied or understood?
- Is there a gap between the ideal of providing safer seismic buildings and the reality of what is being provided?

The Need for “Expertise” in Seismic Disaster Reconstruction

It should be noted that the performance based approach inherent in the three stated objectives at the start of this paper are not usually stated in codes and they assume that the designer is an experienced seismic designer and therefore will ensure that the overall seismic strategy used is not compromised by details or requirements of the building brief.

This position is stated by FEMA 273 (1997) that “The engineering expertise of a design professional is a prerequisite to the appropriate use of the *Guidelines*, and most of the provisions of the following chapters presume the expertise of a professional engineer experienced in building design, as indicated in specific references to “the engineer” found extensively throughout this document.”

And FEMA 389 (2004) goes further: “The application of performance-based seismic design can be highly technical, and requires that the design engineers have a good understanding of seismic hazards, and the dynamic and inelastic behavior of buildings and materials. Unlike the application of building codes, performance-based seismic design is not typically prescriptive in nature, and often requires significantly more detailed building analysis than might otherwise be required. However, as discussed earlier, the advantages of performance-based seismic design in the development of an overall risk management plan is usually worth the extra effort spent by the design team. It is the challenge of the design team to convey this level of importance to the owner and the owner's representatives.”

This need for experienced people in the field is backed up by da Silva’s comments about the design situation in Banda Aceh during the tsunami reconstruction that she characterizes as “optional” (da Silva, 2010). She writes “After the tsunami the need to design for earthquakes was overlooked strategically by BRR (The Indonesian Government’s Agency charged with coordinating the reconstruction) and many implementing agencies. BRR justified the fact that most of their construction was not seismically resilient on the grounds that to make it so was probably cost prohibitive and that reconstruction timescales did not allow for additional design time.” This comment should be judged against the regular occurrence of earthquakes in Aceh in the years following the Asian Tsunami on December 26 2004. Large earthquake events (7+ on the Richter scale) present “swarms” of smaller earthquakes and are not one singular event. Thus, BRR’s position is difficult to understand.

However, she continues that there was an issue with “DEC’s (the Disasters Emergency Committee based around 13 UK based humanitarian agencies) Strategic Framework (that) specifically referred to reducing vulnerability to natural hazards. However, in practice the extent to which DEC Member Agencies appreciated the importance of seismic resilience, and how to achieve it, was largely dependent on the degree to which they employed external expertise, and the timeliness of this advice in shaping their proposals.” And hence the need for people experienced in disaster response that understood how humanitarian agencies work and had a background in seismic design. One is left wondering about the post disaster situation in Haiti.

She goes on that “Many agencies experienced challenges in achieving adequate seismic design. Some had to demolish and rebuild houses and others retrofitted solutions to enhance seismic performance.” There was confusion over codes and standards promoted through the UN Humanitarian Information Centre (UNHIC, 2005) that resulted in a “prescriptive” specification for various building elements that “failed to include basic good seismic design practice in relation to symmetry, openings, wall panel sizes, ring beams, ductile reinforcement detailing and ties between elements. Several agencies complied with the (prescriptive specification) assuming that it was sufficient or that local designers and contractors knew what they were doing without realizing that safe construction practices were not common practice”.

Moreover, “local engineering consultants employed by implementing agencies to develop structural designs generally had limited experience of seismic design, which typically requires an additional post-graduate qualification. This resulted in poor design solutions, which were not compliant with the Indonesian (building) code. Recognizing this, some agencies employed specialist international consultants or firms to develop or check designs, or sought advice from local and national universities. International engineers were also employed as consultants in-house. However, many of these engineers did not previously have seismic design experience and so were ascending a learning curve, trying to follow available guidance and incorporate it into the construction drawings." Her analysis of the design situation in Aceh is both sensitive and accurate and perhaps also prophetic in its application to other seismic disaster reconstruction situations.

Hence, it would appear that these three specific areas of seismic construction are "common place" in reconstruction given their importance in FEMA documents back as far as 1997 and still current in 2004. And while an experienced seismic engineer would be expected to be aware of these issues their importance was not understood by the 13 members of DEC. This suggests that the principles of good seismic design in post disaster reconstruction are not being applied or understood.

Codes

The three specific areas of seismic construction are not specifically mentioned in codes and standards but are inherent in their provisions. For example, most codes do have requirements for vertical changes of stiffness. The New Zealand seismic code restricts such changes so that (NZS 1170, 2004): "…vertical stiffness irregularity shall be considered to exist when the lateral stiffness of the primary structure in a storey is less than 70% of the stiffness of any adjacent storey, or less than 80% of the average stiffness of the three stories above or below."

What does this mean in practical terms? If for example, the lateral load resisting structural system in a building consisted of one six meter long reinforced concrete wall, then changing that length to 5.33 meters or less would be sufficient to generate a vertical stiffness irregularity. This relatively minor change would be sufficient to initiate a soft storey response of a building and the resulting failure shown earlier in table 1.

In a similar way, brick infill walls and stairs that are unintentionally bracing the building can also impact on this vertical stiffness irregularity. But other than this reference there is not other recognition of these three specific areas.

And while this criteria for vertical stiffness irregularity is also embedded in most US based codes and guidelines (such as ATC, FEMA, ASCE, UBC, IBC, NEHRP), the Euro code and the Indian code, the lack of expertise means that it is over looked as described earlier by da Silva.

In addition, the use of brick infill walls is not economical in many economies and hence seismic factors are not included in the codes or in the associated seismic literature. Much of the "brick" focus is on the seismic strengthening of older historic and heritage type buildings. Nonetheless, it remains the construction practice of choice in many economies and this gap in the seismic knowledge between economies further adds to the gap experienced in the field.

Building Torsion

One further aspect is that the use of brick infill and the bracing effect of stairs has the potential to throw the building into torsion. This significantly increases the seismic loads on those columns furthest from the wall or stair. Charleson explains that this can be easily achieved when infill walls are on one boundary of a building (Charleson, 2008). And his chapter on "Non structural elements: Those likely to cause structural damage" specifically mentions infill brick walls and the bracing effect of stairs as the two major causes of structural damage. He suggests several isolating details but it is clear that infill brick walls and the bracing effect of stairs represent major seismic hazards particularly when they induce torsion in a building.

The Indian Seismic Code

The adoption of so-called "advanced" codes such the UBC (Uniform Building Code) in countries where brick infill is used (as has occurred recently in Pakistan) means that designers will not have any direction on what seismic design factors to use. The Indian Seismic Code on the other hand does and this excellent well-written code is the basis for table 2 below that compares the seismic impacts of the 3 specific areas of "unintentional" seismic construction.

Table 2. The Impacts of the Three Specific Areas of "Unintentional" Seismic Construction Based on the Indian Seismic Code.

Aspect Type	"R" value	Effect on loading	Structural issue and comments
Ductile concrete frame	5	Benchmark 100%	This is the benchmark structure.
Infill brick walls	1.5	110% increase in shear (columns base) Reduced bending moment	The large relative stiffness of the brick wall compared to the concrete frame means that the frame-wall responses as a brick wall R=1.5 which is 5/1.5= 3.33 times higher seismic load than what the frame is designed for. This is increased by a further 10% for the shear load at the column base, so overall a 367% increase in seismic load. In addition there is the potential for torsion on the building depending on the relative position of the wall.
Stairs not isolated from the building	For stairs R= 3	Not relevant but frame load generally reduced	The stairs are not designed for the seismic load and hence potential for collapse of the stairs. In addition there is the potential for torsion on the building depending on the relative position of the stair in the building.
Soft Storey	Not allowed in the code as discussed earlier.	100%	All of the ductility demand is concentrated into one floor. This usually results in premature building collapse as shown in table 1.

The noticeable impact is for infill brick walls that potentially result in a 367% increase in seismic load due to the change in ductility capacity caused by a change in material (brick now included as part of the infill) and a change in the structural system (from a frame to a shear wall). These increase the seismic load and then the structural action of the infill concentrates that load as a shear force at the base of columns. This occurs because the infill walls forms a diagonal strut when the infilled frame is loaded laterally. Columns are not usually designed for a 367% over load and the usual result is a shearing off of the columns and hence premature failure of the frames and the infill system.

The stairs are not usually designed for bracing loads and hence could be expected to perform poorly as seen by the snapped stair in table 1. The loss of access would hamper any immediate evacuation of the building and any subsequent search inside the building. But there is also the potential for both the infill wall and the stair as outlined earlier to induce torsion in the building causing premature failure of the distant columns.

Soft storey is not allowed and is referred to as a “weak storey” (defined as 80% of the “strength” as opposed to the “stiffness” of the floor above) in the Indian code.

Therefore, it would appear that these three specific areas of seismic construction do represent major seismic hazards.

Confined Masonry

The use of this structural approach has become popular in trying to make the infill brick wall and the reinforced concrete framework together given its apparent economic advantage over other forms of building construction. It also seems to have become a default position for those that perhaps belatedly discover the issues of infilled walls outlined in this paper. Nonetheless, despite looking the same there are several significant structural and construction differences between confined masonry and infilled masonry that are as follow (Schacher, 2009):

- Confined masonry is designed for a lower R Value (and hence higher seismic load and lower ductility) than concrete frames that are (unintentionally) infilled with brick. The seismic load on a confined masonry wall is between 1.20 to 3.33 times (and probably more to the 3.33) larger than an infilled frame.
- The brickwork in a confined masonry wall is designed and constructed for a specific shear stress. An infill wall is not designed for any specific stress other than good practice.
- The concrete columns of a confined masonry wall are cast after the brick walls are constructed so that the two are physically locked together. The columns in infilled frames are cast first and then the bricks laid up to infill the frame. The introduction of nominal steel ties between such columns and the brick walls does not effectively lock the two together as required.

Thus, these differences mean that this approach can be differentiated from infill brick walls in field photographs.

Research Objective

To establish the need for timely and expert seismic input into seismic disaster reconstruction.

Research Results and Discussion

The results of this paper consist of corroboration of the three specific areas of “unintentional” seismic construction taken from the seismic literature and guidelines coming from recent seismic disaster reconstruction. This was supplemented by photographs from the author’s own observations in seismic disaster reconstruction. The sources for either are not identified but the Internet material is public domain and could be found using basic Google type searches. The existence and the ease of finding such material (using the process inherent in the “theoretical” discussion thus far) would support the idea that there does exist a gap between the ideal of providing safer seismic buildings and the reality of what is being provided. This is the 4th and final research question expressed earlier.

Material was sourced via an Internet search and sought material in a book, guideline or report format intended to be down loaded and presumably used. This material was then reviewed down to the selected material presented below.

The first in fig. 2 are of particular relevance as they are from an important UN guide on good building design and construction for Banda Aceh, Indonesia. The two on the left show a soft storey construction despite getting a green tick for the raft foundation on the left and being elevated in the middle photo. The middle photo gives a sense of the number of houses. The photo on the left got a green tick for tying the infill brick walls by steel rebar.

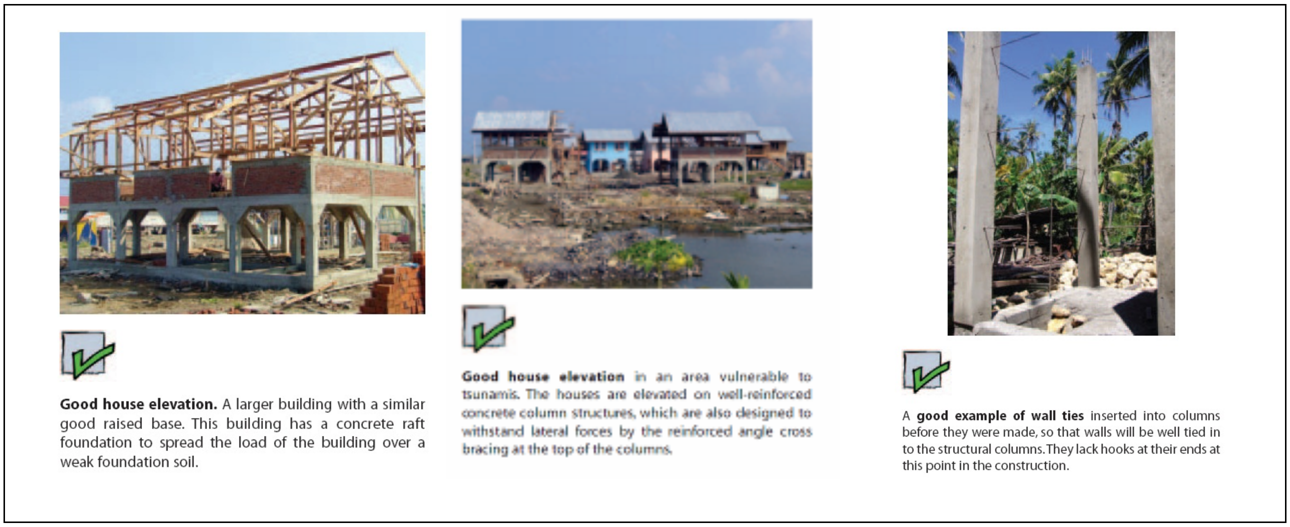


Fig. 2. **Examples of Good Practice for Banda Aceh, Indonesia**

There is no consideration in these 3 photographs or their associated narrative of the impact of the soft storey or the infill brick on the seismic response of the buildings despite being in Indonesian seismic zone 5 that has peak ground accelerations of 0.29 to 0.36g. The site appears to be closer to 0.36g (flexible soils) than 0.29g (rigid soils). The knee stiffener in the concrete frame could also be problematic as it changes the structural action of the frame and depending on the selected R Value could result in shearing the column off at the base of the knee.

The front cover of that same publication in fig. 3 below shows two further examples one (top left) of a soft storey that also has a torsional issue and (bottom left) a brick infill frame.

Fig. 3. **Front Cover**

The examples in fig. 4 are from another international organization. The narrative to the photograph on the left promotes the virtues of the local culture to “get on with the job” following the Yogyakarta earthquake. But they have apparently built back exactly what fell over in the earlier earthquake. The writer strangely also admits that additional unspecified bracing was added to the frame and that smaller vertical rebar and stirrups were used. That aside, it is another common example of brick wall infill and there was no reference on how the design may have been amended to prevent collapse in the next earthquake.

On the right of fig. 4 is a recycling example using brick rubble wall and cement mortar mix to construct infill brick/concrete walls. Other photos in the report show minimal reinforcing and while the use of rubble is a good idea the casting of the infill wall between the columns of the frame has the same effect as infilling with brick.

Fig 4. **Reconstruction in Yogyakarta**

Both examples were aimed at mobilization of communities in post-disaster construction, which is excellent but probably lacked seismic expertise and input.

This final example in fig. 5 below, perhaps underlining da Silva’s observations for the need of engineers with seismic experience as it comes from an international engineering consultancy. While it contains good advice on the planning, materials and construction of the house it does not mention the need to review and ensure that the correct seismic load is used. As indicated earlier this can mean an increased seismic load of possibly 367% over a reinforced concrete frame and seems particularly relevant given the included planning advice.

Fig. 5. **Brick Infill Walls Engineering Advice**

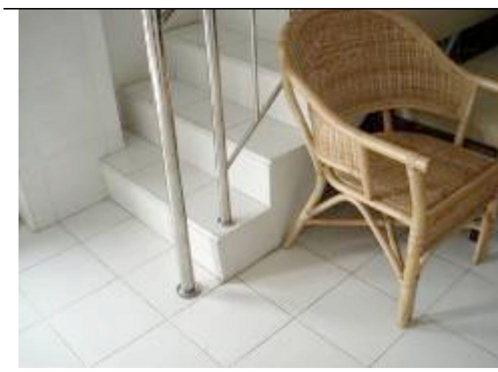
Hence, buildings can “tell” a lot about the program that is producing them. These few examples are not a strict scientific survey because of the context in which post disaster reconstruction operates but their source and the significance of the seismic issues involved should be of concern. And while there would be agreement that “Good Engineering without Appropriate Communication doesn’t lead to Seismic Risk Reduction” as suggested by Schacher, the ability to first achieve the good engineering could be problematic by itself (Schacher, 2008).

Finally, tabulated below in table 3 are selected photographs taken by the author on projects that he either worked on or inspected in the last five years. It was from these sorts of projects that the idea for the three specific areas of “unintentional” seismic construction originated. The first rows are examples of staircases tied into the structure that unintentionally brace their respective buildings, designed by a local consulting engineer. The hospitals or day clinics that would have been designed for a longer return period than the 500 years were usually adopted. These are in Indonesia.

In the second row, examples of a four story Government departmental building in Pakistan comprises all three of the specific areas. The reinforced concrete entry stair case is tied into the building (and also generates torsion within the building), it has a soft storey at ground level and the concrete block walls in the upper 3 floors are tied into the reinforced concrete frame structure of the building. An international engineering firm designed this building.

The third row shows examples of different larger infrastructure buildings in Pakistan such as power substations and key warehouses that have infill frames and soft storeys.

Table 3. **Areas of “Unintentional” Seismic Construction**

Conclusions

There is a desperate need for agencies to realize the role of seismic expertise in all stages of any post disaster reconstruction program. This paper suggests that this message was not understood or heard by those initiating reconstruction in the past and concludes that:

- The three specific areas of seismic construction do represent major seismic hazards.
- Their presence is evident (but not necessarily “common place”) in reconstruction.
- Their presence does suggest that the principles of good seismic design in post disaster reconstruction are not being applied or understood
- And finally that there is a gap between the ideal of providing safer seismic buildings and the reality of what is being provided.

If the objective is to build back better, to create more resilient communities and to reduce a poverty cycle generated by loss of homes, infrastructure and lives.

Key Lesson Learned

- The three specific areas of seismic construction can be easily and readily used to interrogate photographs of the reconstruction to get a sense of whether a program is achieving the usual minimum seismic standards.

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