

STRUCTURAL QUALITY CONTROL IN THE FIELD

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Abstract

The quality control of structural elements for post disaster reconstruction in the field is problematic. Test facilities are often remote, training can be inadequate and the attitude of suppliers and contractors can be negative towards such controls resulting in a less than adequate construction. This paper outlines several techniques that have been used to address such issues including the following:

- **Foundation checking using Scala Penetrometer testing**
- **Concrete strength testing using Rebound Hammer testing**
- **Rebar placement using Cover meters**

These are all tests that can be completed in the field and give immediate test results that can be repeated if required and provide positive evidence for the doubting suppliers and contractors. Such tests have been used in housing projects in Banda Aceh, Sri Lanka and India with this paper focusing on the context in Banda Aceh, Indonesia.

Keywords: Quality Control, Testing, Structures, Housing, Seismic

Introduction

Many aid agencies responded to the need for permanent housing following the Asian Tsunami of 26 December 2004. In Aceh Indonesia, agencies had to deal with the usual challenges of a lack of skilled trades people and professional staff in an unregulated building industry that seemed to readily accept low quality work. Nonetheless, aid agencies were mandated to provide “durable” houses, that were “sustainable”, that allowed people to live in “dignity” and to advocate housing as a basic “right”. This meant that houses had to be seismically “safe”. The houses in Aceh typically consisted of reinforced concrete frame structures with bricks walls, timber truss roofs and corrugated iron roofing with the reinforced concrete frames providing the seismic bracing.

The poor quality of construction and concerns about the durability of the houses being constructed soon lead to a discussion of what was “good enough” under the challenges of a post disaster reconstruction economy as outlined above (World Vision, 2007). Then in the height of this issue, agencies realized there were also serious seismic design shortcomings and that the

construction documentation they had been working to was flawed. These design flaws were due to the following main design issues (New Zealand Society of Earthquake Engineering (NZSEE), 2006):

- The mass of the brick infill walls in seismic calculations was ignored as being “non structural” thus reducing the design seismic loads by around 50% of what they should have been.
- The selection of the highest seismic factor R (=8.5) that would ensure the lowest seismic load was automatically done but not reflected in the remainder of the design. The “R” value reflects the type of structure selected and as detailed should have been between 3.5 and 5.5. Consequently, seismic loads were reduced by 35-60% than what the house should/could have been designed for.
- Brick walls were not isolated or separated from their concrete frames thus compromising the seismic performance of the frames. This was connected to the R-value issue above and with such a structural system an R-value between 2.2 to 3.5 should have been used. Consequently, seismic loads were reduced by 60-74% than what the house should/could have been designed for.
- Finally, there were inadequate details for joints, potential seismic hinge zones and confinement reinforcing shown on the drawings together with non-seismic detailing of ties.

These aspects appear to have been commonly accepted by structural designers in Aceh. Nonetheless, it meant that the house design would not meet the national building code standards¹ (though in Indonesia house design follow a guide put out by the Public Works Department² that has lower criteria) or international standards even if the stipulated material qualities and strengths were achieved. Agencies were divided over whether they had achieved satisfactory seismic compliance because of this split but for the aid agency in this study there were two major structural issues to be addressed that were as follows (ARUP, 2006):

- 1) The seismic design of the houses being built was less than would be acceptable in other countries.
- 2) The material quality and strengths were poor.

In reality, both issues were further compromised by unauthorised substitution and changes on site such as 12mm diameter column reinforcing being changed to 10mm, 8mm diameter column links being changed to 7mm and column cages for a smaller 150x150mm column being used in a 200x200 mm column. Thus, to adhere to their mandated values required an assessment of their significant building programs that had been running for 4 years.

Houses were seismically redesigned and a more instrument based testing regime implemented and this paper reviews the role of the testing regime adopted by this agency and it's application to approximately 1,100 houses on both original sites (those retuning home) and new sites.

Research Method

The paper uses a case study approach from which general conclusions are suggested. The research hypothesis is that a SMART approach to structural quality control can bring about a cultural shift in post disaster reconstruction. The SMART approach is a mnemonic often used in project management that stands for the following³:

¹ Indonesian Seismic Loading Code SNI 1726 -2002

² Referred to in Indonesian as the “Petunjuk Pembuatan Rumah Sederhana Tahan Gempa”. It is a set of recommendations that do not reflect the seismic zone, foundations conditions or structural type factors in the building code.

³ Doran, George T. "There's a S.M.A.R.T. way to write management's goals and objectives." *Management Review*, Nov 1981, Volume 70 Issue 11.

S Specific, M Measurable, A Attainable, R Relevant, Realistic, or Results/Results-focused/Results-oriented and T Time-bound. While this sounds straightforward the reality is that in developing economies under the typical shortages of skills and resources in the post disaster context doing what seems reasonable is invariably difficult.

The overall post disaster context in Banda Aceh (as outlined earlier) is more specifically described by da Silva (da Silva, 2010) “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.” She continues that there was an issue with the Disasters Emergency Committee (DEC) Strategic Framework. DEC is an alliance of 13 large UK based humanitarian agencies and the framework “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.” Moreover, “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 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”.

Finally, she adds that “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.”

This case study (unfortunately) appears to be typical for other aid agencies in Banda Aceh and potentially for other seismic disaster reconstruction such as Haiti. But, the sensitivities involved have meant a scarcity of public discussion and literature despite the “pain” and apparentness to those in the field as inferred by da Silva’s description. This is in part the reason for this paper that seeks to show another alternative approach of resolution through appropriate quality control measures and consequently the use of a more quantitative research approach.

Research Question or Research Hypothesis

- Were the in field quality testing procedures selected effective?
- Could these be used in other housing programs?

Research Context

A Culture of Change

Any decision to change plans in the middle of construction is difficult. A significant amount of effort, consultation, design and procurement had already been invested in the plans that this agency was using for their house construction and hence acceptance of the need to change was painful at all levels of the agency. The quality issues in the field and the seismic re-design of the houses highlighted three key areas:

1. There were no house plot specific tests of the soil bearing capacity.
2. The strength of the concrete was always going to be questionable given that it was being manually mixed on site.
3. Reinforcing was firstly not placed accurately and was also not rigidly held in place and hence moved when the concrete was placed.

Contractors were not building to the drawings or specifications but were making changes on site without any reference or authority as indicated earlier. Moreover, the structural quality process at this point was based on a visual inspection that contractors often plastered before they could be inspected. This was the norm prior to the tsunami.

On the inspection side, the construction supervision staff was not sufficiently skilled or sufficiently confident to insist on the contractors (who were usually local elders or leaders) complying with the construction documents. The resulting poor quality was to be expected. In some cases, it was so poor that instead of being “low strength” it was “no strength” concrete. Hence, this “building culture” was the issue to be addressed.

The importance and place of the structural design of the house was not appreciated and this was where the first need existed. In seismic design the selection of the design strategy (represented by the selection of the structural system’s material) sets the areas for absolute quality control and detailing of the remainder of the house and in particular, the selection of the seismic “R” value. What is perhaps not understood is that seismic loading on any building or house actually depends on the selection of this R value and the higher the R value is, the lower the seismic load that the house needs to be designed to. Buildings are not usually designed for the full seismic loading of an earthquake. Requirements for windows and doors usually mean that some lower level of seismic load is selected. However, this lower seismic loading comes at a cost and it requires more stringent design and control of the ends of beams, beam column joints and columns bases. Designers will at times use a lower R-value and accept the higher seismic loading as it results in easier, faster and more economical construction. Again as outlined by da Silva, this was not coordinated or understood within either the aid or the local structural community and only to a limited extent in the international engineering community.

Other Challenges for Testing

In addition to being aware of this complicated “cultural” climate were more practical issues related to the logistics of any testing and quality control. The testing needed to address the following:

- It needed to be robust
- It needed to be straightforward
- It needed to be immediate
- It needed to be portable
- And it needed to be quick

Consequently, the testing equipment selected for this work consisted of the following:

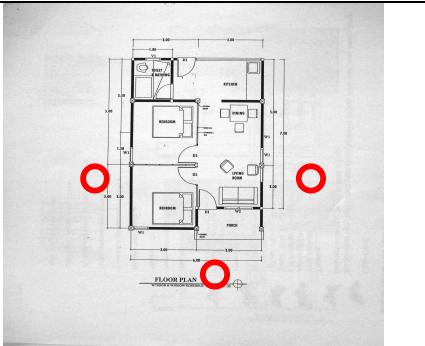
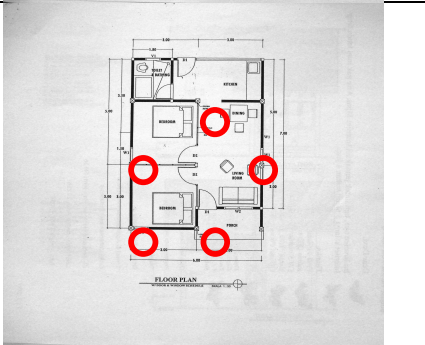
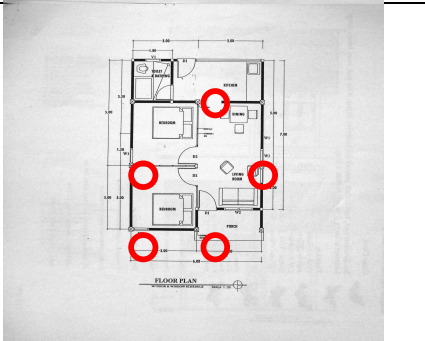
1. A Scala penetrometer for testing soil-bearing capacity (cost \$300 US). This NZ/Australia invention measures the depth of penetration of a standard cone under the impact of a 9 kg weight dropped 510 mm (New Zealand Standards Association, 1988). It satisfied all of the above criteria but did need work back in the office to get final results.
2. A rebound (or Schmidt) hammer for checking concrete strengths (cost around \$1,000 US). This measures the rebound of a steel plunger driven into the concrete by a known amount of energy (ASTM International, 2008). This satisfied all of the criteria though operators did require practice to coordinate the locking of the plunger after being driven into the concrete.
3. A cover meter for locating reinforcing (cost \$5,500 US). This measures the flux associated with the steel reinforcing and satisfied all of the criteria but it was relatively expensive compared to the other equipment.

The interesting part was the “cultural” impact of these testing procedures.

The Development of Testing Criteria

The implementation of the quality system came after most of the houses had been constructed. Thus, the design mentioned earlier became the basis for the design of retrofitting for houses yet to be constructed but also the testing criteria for houses that were substantially complete.

Table 1: Test Locations

Structural Quality Test	Test Locations
<p style="text-align: center;">Scala Penetrometer</p> <p>3 tests per house (1 on each side and 1 in the front) Bearing capacity at the founding level of the pads required. Test to 1.0 metre below footing. Note water table depth.</p>	
<p style="text-align: center;">Rebound or Schmidt Hammer Testing</p> <p>5 tests per house on the 200x200 columns are shown in the plan. Tests to be around 300 mm above floor level and in the core of the column. Testing should be to the concrete rather than plastered finish. Take 5 readings minimum at each test location. Record readings in MPa units</p>	
<p style="text-align: center;">Cover Meter</p> <p>5 tests per house to confirm the size of the vertical rebar and the cover of the 5 200x200mm columns indicated on the plan. Record the outside to outside distance between vertical reinforcing in the indicated columns.</p>	

The criteria associated with the three key quality areas identified above were as follows:

1. A minimum allowable soil bearing capacity of 75 KPa under seismic loading. This was based on the correct seismic loading being applied to the building.
2. A minimum concrete strength of 10 MPa. This was a low value and in many countries would possibly not be called concrete. It was also accepted that at best rebound hammers had a repeatability of $\pm 20\%$.
3. A minimum outside of reinforcing to outside of reinforcing of 90 mm for columns. With 12 mm diameter column reinforcing this represented a gap between the vertical rebar of 66 mm. This was required to ensure sufficient structural action of the columns.

These were measured at the sites identified in table 1.

Insufficient soil bearing capacity at any one of the three test locations constituted a fail and a recommendation to demolish regardless of the other test results. If that was not the case then the house needed to achieve at least three passes from the five test locations for the remaining two tests to pass.

Research Objectives

- Ensure structural quality control in the field for the programme and ultimately to construct durable and seismically safe houses.

Research Results

The quality-testing regime was then applied to 1,096 houses over a two-month period using two teams of between three and four people each. These teams were lead by Chang and Zuo in the field with support and visits by Potangaroa and Wilkinson.

Each team was able to completely survey around 10 houses per day. It was planned to do scala tests first and to eliminate houses with foundation issues. This did not prove to be feasible and teams found it logistically easier to sweep through doing all the testing at once rather than just the scala and then re-visiting. The scala test proved to be the slowest and the most physical of the 3 tests. It required a minimum of two people but was more comfortable with three while one person could do the other two tests. A third month of data processing completed the testing and set up the locally based teams for ongoing construction monitoring.

The houses were spread between four geographical locations, two were where people returned to their original house sites which were coastal, usually flat with a high water table (Original1BA and Original2L) while the other two were to new sites away from coastal Banda Aceh and in the hills (New1S and New2J). The break down of the three test results at each location is shown in table 2 below and it generally indicates a poor performance across all three-test areas.

Several of the houses required a 2nd partial or complete re-survey to confirm earlier results, as is often the case. There were many issues locating "original" houses and despite having a sophisticated GIS system, application of the maps produced by this system in the field produce confusion. Houses were not where they were shown and were only found based on local knowledge of that particular person; houses were on different plots and some were in different neighbourhoods. It seemed that while the previous field staff was aware of the changes these were not reflected nor amended in the GIS. In addition, new streets had been constructed but what was perhaps most frustrating was that the same house numbering had been used in different villages. This resulted in re-surveying complete villages. It seemed that changes of staff

and loose control of the input process resulted in parts of the data from different villages being entered into the database. The lesson from this was to create one's own database and use that as the deliverable rather than the field data sheets but the only reason this input approach was adopted was because it was being directly input into the GIS system. There is a need for care when using such technology in post-disaster reconstruction and while there is a "we are in control" feel about the maps that a GIS system produces the practical reality of updating and amending can often mean such information is at best dated.

Retesting was also required in several original sites when it became apparent that the new house had been built on back fill over the concrete slab of the previous house. Thus, Scala readings were simple halted once testing reached the slab and without adequate notes the test was initially recorded failed because it had not gone to the required depth.

Issues of certification and demolish/not demolish assessment also became apparent after the testing had been completed and while one was comfortable certifying the results of the testing the decision to demolish the house solely on the testing data seemed inadequate unless costs were also included. For example, some houses that passed the structural criteria needed extensive replacement of doors, windows and their frames. These would out weigh the cost of starting anew. Additionally, the breakeven cost point between demolition or strengthen was initially estimated at around 40% construction completion, any house beyond that should be strengthen if it passed the testing or not tested if it was less than 40% However, there were two different guides for how this 40% was gauged by the agency staff and the variation in costs for new houses meant that this 40% level was also changing. Therefore, making the decision to demolish or not based solely on the structural testing may not have produced the optimal outcome for the agency and potentially for the beneficiaries. Nonetheless, this was done and the 40% guideline was used.

The overall figures are tabulated in table 2.

Table 2. Test Results

Location	Total House Numbers	Structural Quality Test Failure Rates			House Demolition Numbers
		Scala	Rebound	Cover	
Original1BA	329	28 (9%)	73(22%)	58(18%)	101(31%)
Original2L	390	81(21%)	43(11%)	20(5%)	116(30%)
New1S	188	3(2%)	13(7%)	0(0%)	15(8%)
New2J	189	4(2%)	53(28%)	11(6%)	58(31%)
TOTALS	1096	116(11%)	182(17%)	89(8%)	290(26%)

Discussion and Conclusions

The impact of location (original or new) was apparent in the higher failure rate for Scala testing of coastal (original) compared to hill (new) sites with original sites being between 5-10 times more likely to have poor bearing soils. The original sites were invariably next to ponds or swamps and hence a higher failure rate was not unexpected. It was partially offset by the better performance characteristics of clays under seismic conditions as laid out by Stockwell's work (which is the defacto standard procedure used in New Zealand and Australia for interpreting Scala results) and finally by wider mountain stone foundations (Stockwell, 1977). Moreover, the rural/ agricultural context of Original2L over the more urban Original1BA is perhaps evident with the former being 3 times more likely to have poor soil bearing capacity than an urban context.

However, this did not carry over into the potential for better aggregates and presumably better concrete that could be achieved in hill sites rather than coastal sites (where it had to be hauled in). Rebound tests were comparably poor between the two locations with the lowest performance

being on a hill site. It would appear that of the 3 tests concrete strength was the hardest to achieve (though a pass threshold of 10MPa could not be described as onerous). Cement is expensive and together with the onsite mixing process used (usually manually and on the ground) and the building culture outlined earlier did give poor results in all areas.

The cover results are interesting in that no failures were recorded for the New1S site and moreover, this site had the lowest failure rates for all the other tests. This was due to excellent contractor used on this site nicknamed “Bridgeman” after his excellent work on the reinforced concrete access bridge constructed. These results probably represent an upper bound of values achievable for the local building industry and while they emphasize the importance of getting contractors that are “engaged” in the project they are not particularly helpful in how to find such contractors when one first arrives. Certainly, the setting up of a structural quality control system early in the process (and preferably from day 1) that produces immediate and direct data in a SMART manner will give conclusions about who are the better/best contractors as soon as could be expected. In addition, once the better/best contractors have been identified, such information could be (but often isn't) shared with other agencies.

It would appear that the need for and the urgency to establish such procedures are perhaps not understood by agencies. For example, there are several humanitarian standards (such as Sphere) but there are none that address the issue of quality and construction standards for buildings (Sphere, 2010). This maybe due to the “cultural” split between a humanitarian approach, (where Sphere applies), versus a development approach whereby other national and international codes are perhaps more relevant (Fitz Gerald and Neal, 2002). Tents typify a humanitarian approach while Permanent houses typify the development approach and hence the transition from Sphere to national/international codes (Boen, 2005). In this case, neither of these provided international aid agencies and their donors with the level of comfort that what they were building was “equitable” or even adequate. Should houses, provided as aid, be of a lower structural standard than what would be required in the donor's country? In part the answer was a “yes” because of the inertia of locally industry in bringing about change. However, the testing regime suggested and trialled in this paper opens up an alternative approach to that change that is direct, specific and measurable.

In conclusion, the terms *standards* and *quality* are often intermixed. Standards are minimum requirements while quality exists somewhere beyond. And while these tests do establish a minimum standard as found in this case study, they do provide a basis to promote a quality of construction beyond simply minimum. The situations that humanitarian aid organisations are faced with are invariably at the lower end of standards and such robust and portable tests as these with their immediate results better define the quality in addition to the required standard of construction.

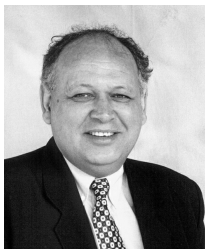
Key Lessons Learned:

- Structural quality control is required from day 1 and should follow a SMART approach.
- The criteria and pass strategy need to be carefully balanced.
- The testing procedures adopted worked well and could be the basis for future programmes.
- Culture, both of the local construction industry and of the aid organisation will impact on the perceived need for a structural quality programme.
- The cultural split between aid and development common to aid organisations surprisingly can interfere with the perceived value of structural testing programmes.
- Contractors and staff appreciated the immediate testing feedback, which mitigated the earlier social stand off between staff and contractors.

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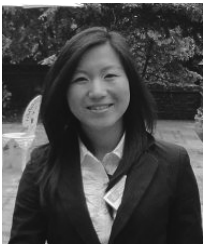
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