Technical Session on Enhancing Rural Construction Culture
HRRP Office, 15th November 2016

Participants: Lumanti, Medair, UMN, Nepal School Projects, People in Need, Helvetas, JICA, Institute of Engineering Tribhuvan University, ICIMOD, ADB, NSET, CRS, Kam for Sud, and Concern.

Introduction

In Nepal, seismic resistant elements in construction have been developed over millennia and reflecting how previous earthquakes and other hazardous events have affected people's homes. It is suggested that working against the traditional construction practices, and introducing elements like cement, concrete, and steel into rural communities which are not accustomed to using these might not be producing safe buildings. The objective of the technical session was to discuss options for enhancing rural construction culture in Nepal and strengthening existing building practices using materials which are appropriate to the context. The session included three presentations; one from CRS on a research project looking at mud mortar improvement through the addition of fibres, one from NSET on research into strengthening stone masonry houses, and one from Randolph Langenbach on the use of Gabion Bands to strengthen stone masonry schools and houses.

The HRRP will be holding technical sessions on different topics every week and details of the sessions will be sent out through the HRRP mailing list which can be joined here and will be available on the HRRP calendar available here.

Mud Mortar Improvement through the Addition of Fibres, Joint Research Project, CRS – Oxford Brookes University – Purdue University

Loren Lockwood, HRRP National Coordinator from CRS, presented an update on a research project, initiated by CRS, looking into mud mortar improvement through the addition of fibres. This a joint research project which CRS is conducting with Oxford Brookes University (UK) and Purdue University (USA). The objective of the research is to identify ways in which mud mortar can be improved through the addition of fibres which can be found locally. This concept aims to find solutions to improve the strength of mud mortar, whilst preserving traditional construction practices particularly for areas where cement is difficult to access, expensive, and is not a material that local masons are experienced in working with. The research includes three rounds testing:

- The first round of testing, which is already complete, was carried out by Oxford Brookes University (OBU). Mud and cement mortar samples with different additives were tested to initial failure, where there is a drop in load, and to total failure, where the sample breaks in two. One of the additives tested was shredded tarpaulin as this is a humanitarian waste product which could be useful to reuse in this way. The most interesting test was total failure, as whether something cracks or not is not necessarily as critical as whether it fails completely. The results of the first round of testing were not very promising, but they did show that there is possibility for complete failure to be slowed.

- The second round of testing was again carried out by OBU, and tested a larger range of fibres and the tests themselves were a lot more rigorous. The testing included three phases; shear tests to investigate impact of fibre density and length, additional shear tests with alternative reinforcement options, and static and dynamic testing of 1m x 1m wall samples. Initially the fibres were chopped up and added to the mortar as this was seen as probably the easiest way to ensure adoption during construction. However the investigations found that longer fibres are better, and these longer fibres work better when they are laid in parallel. In this case cracking could still happen but the parallel fibres allow for stones to hold on and not dislodge as quickly so in theory the building doesn't fail as quickly.
- The third round of testing is being conducted at Purdue University and has just started. This round of testing will focus on dynamic tests of T-shaped stone masonry wall systems representative of typical interior-to-exterior wall joints. The research team is currently looking at the arrangements of the testing panels and determining the parameters of the test, including the findings and recommendations from the first two rounds of testing. It is expected that the testing will be completed in the next two months or so. Three samples will be tested; one wall with no improvement, one with one type of fibre improvement and additional detailing recommendations, and one with other improvements. These improvements will have been pretested in a static situation with OBU under the first two rounds of testing. The shake table at Purdue University is not full size so the samples will be proportionally smaller. For example, wall thickness is 300 mm instead of 500mm.

Q: Can you share the results from the first and second round of testing?

- Yes, the test results are available here

Q: What were the characteristics of the soil used in the mud mortar that was tested? How did you ensure that it was representative of Nepali soil? Did you find any significant disparity between soil properties? Did you find any sensitivities in terms of how the soil composition affected the soil performance?

- CRS collected samples of mud used for mortar in Nepal and these were sent to OBU who analysed it and based on the analysis they replicated the soil composition in the laboratory.
- There were some differences between soil properties, but the researchers were looking for an average of components to work in the middle of the range, for average representation.
- There were sensitivities in terms of soil composition, for example having too much sand or clay affects the way the clay comes together. The engineers conducting the research used the data from the analysis of the soil samples from Nepal to produce a mortar sample that they could work with.

Q: When you include additives in the mortar did the stickiness between the mortar and the masonry improve?

- The research has started to try to look more at adhesive properties and whether fibres can improve the adhesion. It is estimated that natural fibres do increase the adhesion slightly, not because it's stickier but because there are more fibres to grab on to the unevenness of the stones. OBU have not yet completed their final report on the first two rounds of tests, but they will be including some information on this in the report and Purdue University will be looking into this during the third round of testing also.

Q: Did you only test mud mortar or were tests also carried out using stabilised mortar?

- The first round of testing included cement stabilised mortar, but this has been removed for the second and third rounds of testing as the focus of the research is on mud mortar.

NSET Presentation

Ramesh Guragain, the Deputy Director for the National Society for Earthquake Technology – Nepal (NSET), presented an update on NSET's ongoing research related to stone masonry construction. NSET's housing reconstruction programme, 'Baliyo Ghar' ("Strong House" – a USAID funded program), is currently being implemented in Nuwakot, Dhading, and Dolakha districts. This programme does not include a specific research budget but NSET has a long history of conducting research on housing in Nepal, and there are some staff working on 'Baliyo Ghar' who are carrying out some research activities. NSET has strong connections with universities and other academic and scientific research bodies worldwide, and are constantly working to bring these connections to Nepal to support research here. This current research on stone masonry is being conducted with Beijing Normal University with financial support from U.K. Department for International Development (DFID).

Before the April 2015 Gorkha Earthquake, NSET were already conducting lots of research on different types of structures, including looking into the possible safety of earthquake resistant elements from the Nepal National Building Code (NBC). The main purpose of this research is to look into what level of safety can be achieved through the inclusion of the earthquake resistant elements specified in the code. For example, NSET's work pre-earthquake found that construction using masonry with good bricks and cement mortar will fail at around 0.35g, but if bands and other earthquake resistant elements are used then the building is not likely to fail up to 1.0g.

NSET found that it was difficult to conduct numerical modelling of stone masonry because of the randomness of the shape and size of the stones. To overcome this, the stones were clustered in shapes of triangles in the finite element numerical model. Experimental verification looking at crack patterns was used to check this approach and it was found that the numerical simulation results were found to be very close to the experimental results. A force displacement comparison was also carried out for both experimental and numerical modelling. The experimental component was carried out using a small scale shake table, at

1 to 4 scale, at the University of Tokyo. Sand and lime mortar were used in the model. The numerical modelling used data from various earthquakes to simulate collapse in different housing types in Nepal to look at how different earthquakes affected different building types. After the Gorkha Earthquake the numerical modelling was run again using the Gorkha Earthquake data to see how this affected buildings given the long period the earthquake had. The modelling found that whilst there is a difference in the effects, it was only slight.

The numerical modelling was carried out for stone masonry structures with and without earthquake resistant elements as per the NBC, using a DUDBC design from the design catalogue. It was found that where no earthquake resistant elements had been used failure occurred at 0.3g. Where earthquake resistant elements had been used the structure was still ok at 0.5g. There were some issues with stones falling at the main opening but when it was remodelled so that the timber band was expanded this issue was removed.

This numerical modelling needed to be backed up with experimental tests and these were carried out at Beijing Normal University in Kunming, China using a 3/5 scale shake table and in-plane cyclic testing. The research is targeting two storey stone and mud mortar construction as the fear is that households will build a second storey, even if the advice provided is based on single storey construction.

The testing in China included a test using tarpaulin bands, and it was found that these bands were very close together, but the cost is low as they are using water glass with some chemicals that were invented in the university, cheap adhesives, and the tarpaulins. The limitation with this is that the required sand and cement is not available everywhere, so this may not be a useful option for rural areas. The tarpaulin bands came out highest in terms of strength in the testing, but timber bands and gabion wire showed similar displacement for the worst case construction sample using bad stones. The tests were also carried out for the best case construction scenario using dressed stones and good construction practices ensuring strong stone to stone connections. The strength difference between the bad and good construction scenarios was very different but the displacement limited. Wall 1 used timber posts and band, along with gabion wire wrapped around the wall and in bands. Wall 2 didn't use the timber posts and bands, but did use the gabion wrap and banding. The arrangement in Wall 2 was considered a possible option for high altitude areas where there is no good quality timber available and it is too costly to import. Wall 1 performed better in the testing in terms of displacement but Wall 2 still managed to get to nearly 200 mm in terms of displacement and the strength was very good. The gabion wires are not welded, but are made in place and would be relatively easy to carry to mountainous and remote areas.

For the best case construction scenario using good quality stone, with a minimum amount of mud mortar, no banding, and no additional earthquake resistant measures collapse occurred at 0.4g. This standard of construction is very difficult to achieve in the field. The numerical modelling and simulation showed the failure on the side of the door where the physical testing failed on the side of the window, but this was acceptable as there was a very good level of matching between the numerical and physical modelling.

Another round of testing will be carried out in mid-December 2016 and NSET are planning to bring NRA and DUDBC representatives as part of the research team travelling from Nepal. NSET are still searching for additional funding to conduct testing where the timber bands are replaced with gabion or geo textile bands.

Q: What is the size of stones used in the models?

- The stones, and all other elements of the test structure, were scaled down as per the / 5 ratio of the shake table.

Q: What is the process to get approval from the NRA for new / improved technical solutions for stone masonry structures?

- There are procedures in place in the NRA and DUDBC to review and approve technical solutions proposed but all require back up in terms of research, data, testing results, etc. Without this data the NRA and DUDBC cannot make a decision. Rigorous discussion is also required amongst all the stakeholders involved, and recently there has been no group existing to do this. The HRRP is now trying to improve coordination on this and to have more discussions on technical issues. This would help the NRA, DUDBC, and POs as it will improve how inputs from relevant professionals and experts can be provided and speed up review and approval of technical solutions. Theoretically this exists already but operationally is not strong enough so will need to improve. The priority for POs needs to be a collective, common voice on technical issues and solutions. There is also a need to look beyond just technical evidence and consider social and economic factors also.
- The housing grant (300,000 NPRs) has to be one of the main considerations. If technologies are not approved then households cannot use the grant money to implement them. NSET's approach has been to use timber bands and posts as per the NBC, plus the gabion wire as the buildings will meet compliance, and households will therefore be able to access the housing grant but they can also start using improved technologies.

Q: What is the cost of using the gabion wires?

- The additional cost, including materials and labour, for the gabion geogrid wrap and bands is estimated to be 50,000 NPRs. This is on top of the normal building costs, which depending on the building location and the availability of stone locally may cost between 3-4 lakhs.

Stabilising Weak Masonry for Schools and Houses: An approach to Rubble Masonry in Mud Mortar Construction in Earthquake Areas

Randolph Langenbach, of Conservationtech Consulting, presented on the use of 'Gabion Bands as an option to strengthen stone masonry schools and houses in rural Nepal. Randolph had just returned from a field visit to Kavre district with the Canadian NGO Nepal Schools Projects, and was accompanied by John Vavruska, a former Peace Corps volunteer to Nepal, who recently supervised construction of a new school in Nuwakot using the Gabion Band technology.

Langenbach showed that in Bam, Iran after the 2002 earthquake there were calls to ban earthen construction, but it was found that 150 year old structures that had been abandoned when people moved out of the old walled town had not collapsed, and had very little evidence of damage from the earthquake. He also found that the thicker the wall the more likely it was to collapse, which was counter intuitive. He also found widespread evidence of termites in the walls. This led to investigations in material science rather than engineering, looking for evidence of causes of a loss of cohesion of clay. It was found that the loss of cohesion in the clay which may have been from an excessive drying out of the walls combined with the overburden of modern restoration work had led to the collapses when the earthquake struck. Modern practices had seen the introduction of wheat straw to stucco the walls annually, which was like a banquet for termites, where the shredded palm bark used traditionally was much better. Following his lectures and publication of his findings, he was told that archaeologists and engineers in Iran started to look for termites across other heritage sites in the country.

In Nepal the Gorkha Earthquake caused wide scale collapse of stone buildings in rural areas. It was surprising to learn how extremely vulnerable the buildings were, that is, lacking the kind of seismically resistive features found in Kashmir, given how many earthquakes have occurred in Nepal over the years. Randolph had visited Nepal previously with the Kathmandu Valley Preservation Trust to look at heritage preservation in the valley districts. Following the earthquake, he visited a rural village in the Dhading district where characteristics of the building failure included corners vibrating at different levels and pulling apart and where the absence of connections to floor diaphragms caused gables to collapse.

The Canada-based NGO 'Nepal School Projects' schools used a classic school structure that can be seen all over Nepal. The schools are usually sited on a plateau, where vibrations from the earthquake were worst. It was seen that the school design is essentially all timber along the front wall, as it is customary to have all the windows on the south side. Partition walls in the schools have no support at all because there is no horizontal attic floor. This is effectively a timber framing system on one side of the buildings with load bearing stone walls on the other sides, and in the partitions between the classrooms – a combination that leaves the stone walls vulnerable to being thrown over by the flexibility of the timber parts of the structure.

Similar examples were shown where steel frames were included in stone masonry structures. Examples included a school in Sindhupalchowk and a house collapsed by the recent earthquake in Italy. In these, the different vibrations of the materials had led to the collapse of the structures. Aerial and on-site photos from Amatrice in Italy showed how modern work interfered with the natural behaviours of traditional stone buildings putting them more at risk of collapse. It can be seen that the mixing of traditional construction technologies with modern elements does not necessarily lead to safer structures.

Taking his observations of structures back in time, Langenbach showed that horizontal banding can be seen in Hadrian's Wall dating from to Roman times. In Turkey there are examples of horizontal bands shown that go back 1,500 years. In the 1918 'Gaddi Baithak' wing of the Hanuman Dhoka Palace in Kathmandu it was assumed that it was all mud mortar but recent research has found that every 1.5 – 2 metres there are three brick courses laid in lime mortar, similar to techniques used in Roman times. In Kashmir, Bhatar and Dhajji Dewari, which use timber lacing and timber and masonry infill-framing, have both proved to be resilient in earthquakes. Timber-laced bearing wall brick and stone masonry is now written into the Nepal and Indian building codes, although with the inclusion of embedded vertical posts which Langenbach identified as a potential problem in earthquakes (See DUDBC Submittal #2 at www.traditional-is-modern.net/nepal.html for an explanation).

In Nepal there is a shortage of timber, but concrete bands which are already in the building code are hard to construct in remote areas where it is difficult to transport cement and steel. It has also been seen that concrete bands used with stone masonry may not be as helpful as originally thought. Wire mesh was found to be readily available in Kathmandu and also in rural villagess so the 'Gabion Band concept was developed where ring beams are formed out of wire wrapping around a single course of masonry.

A US based Public Broadcasting System (PBS) documentary was filmed in Dhading in August 2015 to capture the construction of the pilot Gabion Band house. The approach was found to be easy to teach, and local people are able to adopt the technique into their construction. Instead of the gabion wire it is now preferred to use polypropylene or polyester geogrid as it is generally easier to work with and less susceptible to moisture corrosion. Essential to this approach is still the need for overburden weight on the masonry walls, and an attic floor diaphragm. He showedwhere a double Gabion Band at the top of the wall would be hidden under the roof structure on a parapet going up beyond the floor of the attic, so that the weight of this overburden of stone on the wall below serves to hold the floor diaphragm in place.

Langenbach concluded his talk with a very different recommendation in addition to the Gabion Bands. He described that during the recent field visit for Nepal School Projects, he also discovered that people had temporarily taken barns and made them into houses while they are waiting to reconstruct their house. These were constructed with walls made of bamboo and mud – materials that are readily available in the local context. There is however a feeling amongst the community that this cannot be a permanent house. Despite this, in the example he showed, the mason who had built it estimated that the walls could last 15 years with periodic plastering. Given the context, and all the building work that needs to be carried out, Langenbach recommended that there needs to be a discussion of this option in addition to the reconstruction of stone masonry houses and schools.

Q: How can approval of new technologies such as this be more effectively handled?

- The Gabion Band concept has been with DUDBC for review and approval since January 2016, and the challenge of approving new technologies is something that many organisations are facing. It is hoped that further research of the Gabion Band concept can include testing at UC Berkeley, on the second largest shake table in the world.

- It was highlighted that whilst it is a challenge to get new technologies approved it must be recognised that Nepal is very fortunate to have low strength stone masonry already included in the building code. In Pakistan following the 2005 earthquake, the local traditional technologies of *Dhajji Dewari* and *Bhatar* were not included in the building code and households were required to reconstruct using concrete blocks and concrete frames if they wanted to access the housing grant. One year after the 2005 earthquake the Earthquake Reconstruction and Rehabilitation Authority (ERRA) approved *Dhajji Dewari* and a year later *Bhatar* was approved. There are now almost a quarter of a million new houses that have been built in remote parts of Pakistan using these technologies.

Q: Did you find that masons dumped the stone into the Gabion Bands rather than laying it properly?

- The masons in Mankhu were told not to put small pieces of rubble in the gabion band but this did happen in some cases. Similarly, in Chupar, the masons were instructed to use large flat stones in the bands in the same manner as the masonry courses without bands. The idea though is to modify the building process, not to transform it. The mesh embraces the corners better than timber and it becomes a screed to prevent stone and mud mortar drifting down the collar joint which, in the usual absence of bond stones, can cause the sides of the wall from blowing out.. The Gorkha Earthquake caused very little overturning of the walls in rural rubble stone with mud mortar houses, but many houses collapsed with their walls falling down in place like a bad slump test.

Q: How much does the polypropylene or polyester geogrid cost versus using gabion wire?

- The polypropylene and polyester geogrids cost about 200 NPRs per square metre. For a typical size house this equates to about 400,000 to 500,000 NPRs additional cost on top of the normal construction costs for the traditional masonry construction. It is estimated that the mesh is approximately double the cost of using gabion wire. The change from gabion wire to plastic mesh reflects the fact that it must last the life of the masonry wall. Even with the UV effect, once the bands are plastered with clay or cement, and this is well maintained, the mesh should last up to 75 years, while the galvanized wire showed evidence of early rusting because the welding was done after the galvanizing.
- NSET have completed research on polypropylene bands but found that given the higher flexibility of the material it is not appropriate for two storey houses.

Q: How long does it take to train the masons to build using the gabion bands?

- This depends on the capacity of the masons. The only training required is on how and where to place the gabion bands and how to cut the bands at the corners and wall intersections. For the pilot construction in Dhading an hour long class was held with the masons in advance of the start of construction, and they completed the one room, one story pilot project up to above the lintel band in four days.

Q: Would it be possible to share more details on the structural solutions adopted for the roof on the Chupar, Nuwakot school?

- The roof structure used trusses fabricated on-site from 1.5-inch square steel tubing. The trusses use a "W" design for cross bracing. A total of four trusses were installed on each 3-room school building: over each of the two end walls and over each of the two interior walls that separate the classrooms. The trusses are 30 feet (9.1 m) long and span the total width of the school building plus porch, with approximate 2.5 ft (0.76 m) roof overhangs at each end. The trusses are 5 ft (1.5 m) high at the ridge.

Next Steps

- NSET are currently searching for additional funding to conduct testing of structures using gabion or geo textile bands. Any organisations / donors interested to support this are requested to contact Ramesh Guragain (rguragain@nset.org.np).
- The HRRP will work to provide a space for core technical discussions which can enable a collective and common voice from POs for advocacy on the approval of new technologies by the NRA and DUDBC.
- Other?

Reference Documents

Further information may be found in the following reference documents / resources:

- The Nepal Building Code can be accessed on the DUDBC website - http://dudbc.gov.np/buildingcode.
- There is a wealth of information available on the 'Traditional is Modern' website run by Randolph Langenbach - http://www.traditional-is-modern.net/Nepal.html. A report on the first pilot house constructed using the gabion band technology is available, as are the two submissions to DUDBC regarding the approval of the gabion band design.
- Chupar, Nuwakot school rebuilding project web album link: https://goo.gl/photos/nhut99VBX73Y5fZb7
- Nepal School Projects website: www.nepalschoolprojects.ca

Contact Details

Contact details for the presenters are provided below in order to facilitate follow up on any of the topics covered in the session.

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