Hatıl Construction in Turkey

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1. Introduction

There are many very distinctive styles of traditional rural domestic architecture in Turkey, resulting from cultural attributes, related to material availability and climate. Although once forested many of the hills and mountainsides are now bare. Stone therefore continues to be easily won but timber is increasingly scarce, and so traditional construction detailing is rapidly disappearing. Also, the hill/mountain locations, where timber was once abundant, have resulted from active tectonic movements. It is not surprising to therefore see most buildings that use wood are also in highly seismic areas.

Timber is one main building material used for framed houses along the Black Sea and the Aegean and Mediterranean coasts. Here, square and triangular wall panels are variously infilled with brick or adobe or the structural frame is sheathed in timber planking. There is one small area in the west of Turkey where 'log cabin' type of wooden structures are built. All such wooden buildings, the world over, are noted for their resilience to earthquakes.

Timber has also an extensive history as a main structural 'Hatıl' reinforcing element in rubble stone, brick and adobe houses, the predominant types of houses for ordinary people and especially in rural areas. The reinforcement technique is particularly found along the west coast and throughout the northeastern and central provinces. Stone construction concentrates to the east and adobe in the central areas. All of these areas, particularly the Northeast, are of the greatest seismicity. M_s 4.5 to 5.0 occurs perhaps twice a year, M_s 5.0 to 5.5 occurs once every 1.5 years, M_s 5.5 to 6.0 every 2.5 years, M_s 6.0 to 6.5 every 5 years, and M_s 6.5 to 7.0 every 12 years.

The earthquake resistant value of the timber reinforcement technique has been long noted and accounts for why there is still a Turkish building code of practice that incorporates timber 'Hatıls' (TS 2515). This compares with common knowledge about the poor performance of rubble masonry walls in earthquakes and why its use is officially banned.

2. Rural Construction Techniques

The construction technique of stone with the incorporation of hatıls has been studied in the Bingol district to the east of Lake Van. Here the house construction is by the owner-occupier with the aid of craftsmen who live in the locality but who are not full-time builders. That male house owners all know the rudiments of house construction and contribute to their house building exercise and that their lack of skill is because they only ever build one to three houses in their lifetimes. The craftsmen, however, are usually taught their trade by a father or as a result of apprenticeship. As a result, they have their own tools and, depending on payment and client, can work to various construction qualities. Contractor construction is mostly confined to the full time or part time teams that work on public buildings or who now, as a result of overseas work, specialise in modern concrete construction processes.

As a result of the different types of people constructing houses, it is not surprising to see that construction quality is variable. It is poor when, field rubble is used and bonded with mud mortar, without quoins and with no through stones etc. It is most common when, the stone is worked and 'wedged' into position in the wall core and when some attempt is made to detail the corners and tie in roof beams etc. It has a dressed masonry quality when, the stone is used as ashlar with detailing around doors and windows. The quality and durability is often influenced by the internal treatment of the wall, type of mortar, and the uses of renders. Often, houses are found to contain several qualities of construction with the facades being made to conform to streetscape or to impress the neighbours. Here, the party and rear walls are very inferior.

In all quality of construction the walls, particularly of the older buildings found throughout Anatolia, are hatıl timbers. In the simplest situations they are found at cill, lintel, and eaves levels but can be at 0.5 to 1.0m vertical intervals. In the Bingol region the hatıl technique was common up to recent times but due to the increasing scarcity and cost of wood no new building incorporate them.

3. The 1983 Erzurum Earthquake

On 30th October 1983 an M_s 6.5 to 6.8 earthquake occurred to the east of Erzurum, north-eastern Turkey, and this was immediately field researched by the authors. The event had an epicentre in a rural setting and a significant number of villages over a 20^2 km area were totally destroyed and significant damage occurred in a 40^2 km area. The buildings affected were predominantly rubble stone masonry and many structures incorporated timber reinforcement and had timber roofs. The high level of damage, in a relatively moderate magnitude event, was adequately accounted for by the construction materials, building methods, age, structural condition, and decay characteristics.

The following is a summary of the field observations:

- With just a few exceptions all the different rural structural types used a timber joist system of varying degrees of complexity to support the soil roof covering. The load carrying timber most widely used in the roof was Kavak-Poplar. Examination suggested that the timber roof structures were adequately designed for normal working conditions, but ‘at the time of construction’ only.

- The timber systems were, for many reasons, structurally weak when acted upon by earthquakes loads and when the roof and walls are surcharged with extra soil. In all but the newest of structures beams and columns were round or sub-round in section, the trunk without its bark. This made connections and good bearing surfaces between them virtually impossible, for example, where two horizontal beams cross at right angles and one of them simply rests upon the other. Round sectional beams were prone to roll off the other during the earthquake induced motions. Also, the round beam-ends point loaded (to an excessive degree) the supporting walls beneath.

Photograph 1: Erzurum Earthquake Epicentral Damage

- In many cases where the beams were supported on columns, originally or as secondary strengthening aids, they were flat topped or in a few cases hollowed out to form a saddle-bearing surface. In no cases were rigid fixing mechanisms between columns and beams observed. The load bearing bases of the columns were found to sit on stone plates that in turn sit on the ground surface. While this system is intended to isolate the wood from wet soil, rather than to spread the load over a larger ground surface, it is structurally unsound. It would appear that there was no tradition of sinking columns into post holes or post pits - a method that gives lateral support and somewhat stops overturning actions. Where columns were used in barns, they appeared to be the main method of roof load transfer to the ground. Very little load was transferred to the walls and this often under-utilised the help it can afford to maintaining the performance in compression. In fact, in the absence of any diagonal bracing the main function of the walls is to provide the restraint against hinging and lateral deformation.

- In most structures the roof systems were particularly weak at the wall junctions. There was an absence of wall plates in the older structures and in the modern ones they are undersized, round/sub-round/square, and run along just the top of the inside stone skin. Where round or the more recent square section beams sat on the wall plate the bearing lengths were nearly always too short, for example, about 100mm. This is also the case where the beams were embedded into the wall and in a wall 700mm wide the beam bearings were often no more than 200mm.

- Beam decay was particularly noticeable where in contact with the soil above and in the walls. In most of the timber stacks lying around after the earthquake, and also in in-situ timbers, many types of wet rot decay were present. In standing structures the decay first occurs in the hidden and remote locations where high humidity, dampness and poor air circulation occurs. Many of the timbers were also found to be heavily infested with woodworm of various insect/beetle species – 1 to 15mm holes were present (!) and it is probable that the timbers were already infested before use. In most cases the timbers appear not to have been treated and just the bark was removed exposing the soft sapwood to the decay vectors.

- Secondary joists, that form part of the domed roof type, at the roof periphery were held in position by resting on the top of the inside wall face and the other end on the main beams - often inclined at up to 60^0. The `lath' covering on these joists, and also on the joists of flat roofs, were placed without any form of fixing. In the former case the laths overlap and in the latter case they simply abut. Upon the laths, a layer of brushwood, bracken, or small desert shrubs was used to form continuous matting.

- Generally the timbers in the barns were more seriously affected - due to highly variable micro environment and climate determined by keeping the animals indoors for long winter periods. It was also most noticeable that in barns the beams free of wall-roof contact were the most sound with presumably the air circulation keeping them free from micro-organism attack.

- The use of 'Hatıls' appeared to be restricted to the more wealthy houses of elaborate form and construction. In most cases the hatıls were found on the main facade and front corners. In only a small proportion of the structures did the hatıls go around the side and rear walls to form complete ring beams. In many cases the hatıls were just on the external wall faces - with no corresponding member inside and without `through ties' - and this may result from the upgrading of the structure with a new 'face'. Where hatıls joined at wall corners and along wall faces, the `half lap' joints were of varying quality. In the earthquake, the hatıl systems on the external wall faces fared better. Their exposed position and being made from the hard core wood made then less vulnerable.

- It is interesting to speculate that timber decay is an increasing problem as the houses age. Firstly, as rotten timbers are replaced the new ones are highly susceptible to decay from the surviving vectors. Because houses are progressively using wood burning stoves with long flues circulating smoke from open fires is no longer able to preserve the timber. As the houses become more sound, birds and small animals can no longer pick off the insects that attack the timber. There is a reducing tendency to keep farm animals in the houses in winter.

- Many of the houses had fine facades of rough ashlar blocks with well-keyed quoins and nicely staggered joints. However, it is clear that most of these were no more than a veneer to the less quality building techniques as found in the other walls. The individual stone blocks, while rectangular on the surface, taper back and require wedging into position. This technique is very weak having the load-bearing surface is just the front edge. When the core soil settles or consolidates the rear wedges often readjust and move the stones out of verticality. Also, where the wall has a replacement veneer it will have only a minimal bonding back into the internal core fabric.

Most walls relied on random rubble techniques utilising predominantly unworked sub-rounded to sub-angular bounders probably originating from local stream channels and terraces. These stones are used as external and inside wall skins with no `through stones' for cross wall bonding. With the walls generally being 700 to 800mm thick suitable long stones were found to be rare. The stones were normally poorly jointed and often placed out of equilibrium. Particularly smooth faces makes bonding with soil mortar hard to achieve and the soil mortars usually squash aside to leave the stones in point to point contact.

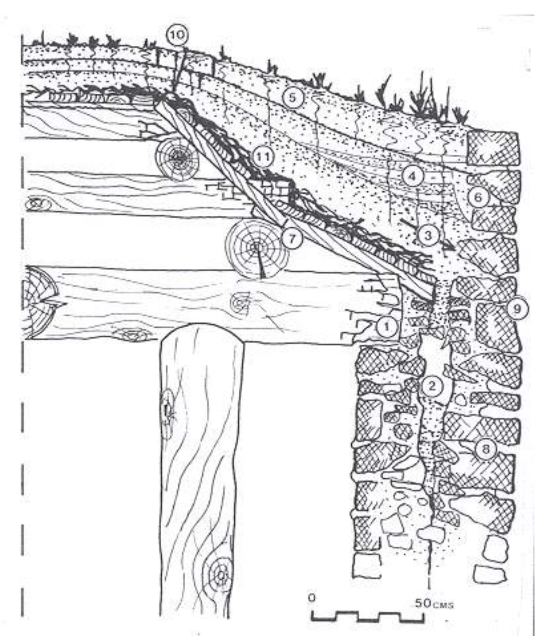

Figure 1: Typical wall construction detail

The wide wall cores relied on mixed small rubble ranging from round to angular shapes. These were placed with varying proportions of soil mortar - ranging from being nearly all stone to nearly all loose soil. It was normal for the top of the outside wall skin to have been raised - as the soil roof cover was progressively added onto. These courses were often more massive stones, with or without mortar, and giving a somewhat ornamental appearance.

- Other external wall defects that were noticed include the occasional use of patches of small stones with thick soil mortar layers and with larger stones layered above. This technique is also observed around window and doorframes - where they are pre-made and stood in gaps - to be packed precisely into position. Small stones were also used in between ashlar quoin blocks producing a vertical line of weakness. Where the quoin system is poorly developed it was noticeable that many walls were built out of plumb, either leaning inward or bowing. This enables water to wash out surface mortar or percolate into the core. Between internal and external wall there was usually very little keying and normally different phases of construction abutted.

- It was very difficult to make comment on the quality of foundation construction. Generally it was said that foundations were constructed to `a depth' rather than to the soil strength. One would think, that where the structures are terraced into the hill slopes, that the deeper soils are much stronger resulting in significant differential foundation settlements. With the front walls being "not more than 50mm deep" water penetration certainly has the potential to soften the load bearing soils under the outside face. It is also probable that walls of different phase have differing foundation characteristics.

During the assessment of the Erzurum earthquake it was possible to achieve a considerable systematic assessment of building damage, utilising field experience gained from working in the 1982 Dhamar earthquake, Yemen. Here, it was shown that with the use of data collection forms it was possible to undertake statistical damage assessment. In this earthquake it was convincingly demonstrated that by sampling building damage in a traverse from the fringe areas to the epicentre it is possible to comprehensively show how buildings progressively collapse, with this being somewhat independent of a time factor. This then becomes the best way to prescribe building repair and improvement methods, rather than responding to just theory. The value of this assessment method is that in the epicentre, the damage is too severe to see how failure occurred. The assessment showed that damage is first triggered as a reactivation of existing damage. New damage then occurs at sites of significant decay, at locations of design weaknesses and then at structurally inadequate locations. Collapse then follows a characteristic sequence for the building type and the one for this earthquake is as follows: - local failure of outside wall skin, area collapse of non load bearing wall, corner or wedge failure affecting non and load bearing junction, collapse of inferior rear load bearing wall with roof failure from one side, and collapse of superior facade load bearing wall with roof continuing to fall.

The selective earthquake targeting, leading to progressive failure, is considered to be the result of the structures being of complex morphology with different resonant responses induced by the ground motions. For predicting damage the fieldwork suggested that - corners are more likely to fail than mid spans, unrestrained spans between two corners are weak points, non loading walls fail before those where there is floor or roof loading, the failure tend to be progressive with increased shaking and shaking time, and failure of an weak element can cause a strong element to become more susceptible to failure.

This scenario is then modified by unique decay parameters, with significant failure firstly occurring around all wall tops, with roof collapse before a whole wall element fails, and then by an instantly occurring granular disintegration if the walls are rubble stone and mortars are loose soil. It is particularly this sort of failure that accounts for the total destruction that was occasionally seen in areas well away from the Erzurum earthquake epicentre.

In this particular earthquake the role of timber hatıls, in modifying the earthquake damage, was not easy to appreciate, but thought to be moderately significant. As previously noted, many of the affected structures were highly decayed, therefore, wall top/roof collapse and granular disintegration occurred. The hatıls systems as seen could not aid in resisting this sort of failure. It was clear that the hatıls when tied around the facade-side wall junctions did aid in reducing the significance of corner wedge failures. It would appear that long doorway and window lintels aided in redirecting crack propagation.

4. Seismic Testing of Timber (Hatıl) Reinforced Walls

During the mid 1980's the Dept. of Architecture, Cambridge University, undertook a research programme of seismic upgrading design for low cost traditional masonry housing in eastern Turkey. Between 1902 and 1986 Turkey had lost over 300,000 buildings due to earthquakes and with building collapse being mostly responsible for the death of some 68,000 people. The main thrust of disaster recovery had been with the appropriate provision of modern buildings in the urban setting. Replacement of rural structures, following many recent earthquakes, has proved remarkably poor, applying short-term solutions, unsuitable design, culturally alien forms, and bad new village sites.

The Cambridge University initiative partly aimed to aid with risk reduction in the rural setting, where it was very clear that most damaging effects are experienced. The project basically involved the examination of building types and their ordinary working performance, the examination of buildings/village/regions after various earthquakes, examination of constructional processes and testing of full scale structures on a Seismic Shaking Table.
In the region, three techniques are typically used for single storey structures. In its simplest form, the house is effectively a box of some 4 to 5m square containing a main room with partitions for kitchen and store. Almost universally the houses have a flat soil covered roof, though sometimes the roof are slightly pitched to help is water run off. The cover is nominally 30cms thick but can be increased to 1m or more to help provide winter insulation. More commonly the rectangular house is modified to have two wings, providing a three main room arrangement and in winter one room is often used for the animals.

The three types of wall construction techniques are common with descending level of sophistication, related to income and social desire to respond to fashion etc:
1) Dressed coursed stone, with large units, narrow joints, single thickness, and thin mortar horizontal beds. With squared timber Hatıls (horizontal timber reinforcement similar to Cators of Pakistan) and jointed corners.

2) Knapped angular stone of regular sizes, placed in semi courses with double skin. wide and irregular mortar beds. Often with dressed stone quoins, With roughly worked timbers utilising lapped and nailed joints.

3) Sub round field rubble, of mixed size, irregularly placed, no through stones and no quoins. Thick straw mortar irregularly placed. Irregular and discontinuously placed Hatıls - if any.

As part of the Cambridge project seismic shaking table testing of such structures took place. The principle aim was to compare the performance of ordinary rubble masonry walls with others appropriately reinforced with timber hatıls and reinforced concrete equivalents and improved mortars. Another aim was to verify the Erzurum earthquake field findings, as to the failure mechanisms and sequences. This work was then seen as an appropriate way to confirm upgrading techniques related to life cycle costing.

The seismic model testing took place on a single impulse table designed and manufactured by the Cambridge team and installed at the Ministry of Earthquake Reconstruction, Ankara. The Table consisted of steel framed-reinforced concrete slab mounted on a set of rubber bushes.

The table was 5.0x6.0m and 240mm thick. The rubber bushes were replaceable and interchangeable for different experimental purposes, varying the stiffness and damping to produce various vibration frequencies. The 20tonne table was supported on a massive reinforced concrete foundation, some 250 tonnes, so providing a very adequate resistance to the motions of the table.

The table is jacked, with the structure built on top, sideways by about 300mm and then released. The table then springs back and forward. The motion is in one axial direction only. The first cycle of motion on the table can be up to a maximum peak acceleration of approximately 2.0g and the rubber bushes dampen the motion to 0.5g on the second cycle and then 0.1 g on the third cycle.

The table was correlated with seismometers, for comparing its design with actual performance - it was found to have a 13% damping slightly higher than expected and probably the result of the structure being cushioned by air resistance. The table also proved to have no torsional effects so it was accurately providing a one-dimensional motion.

Photograph 2: The Cambridge-Ankara Shaking Table with Test House Model

The table is therefore effectively mimicking the ground motion in one pulse for two/three cycles. To copy a 'full' earthquake, the table is jacked sideways and released repeatedly. With the repeated application of 2.0g the table provides a total energy into the walls far greater than experienced in a real earthquake.

For the first experimental programme three test building models were constructed, each 4m square and 2.6m high. All three had the following common features:

1) Limestone rubble masonry with some quoin work.
2) Mud mortar.
3) Traditional roof of 5x10cms joists at 0.6m intervals on wall plate with 200mm soil cover.

The models were built by professional masons accustomed to building vernacular types of houses in eastern Turkey. Their techniques had already been monitored to see how typical walls are built - particularly the internal /hidden details. The masons were therefore well versed in producing the typical wall and not a pukka form that they would normally produce for an international client and one standing over them to see all the tricks of the trade! However, it was surprising that the masons had to be shown the details of pegged/nailed half lap joints. The masons were not shown the use of scarf joints for long members, due to the size of the models and because such techniques were too sophisticated for low cost housing types. The wood for the models had to be reduced from 100x100mm to 100x50mm because of the now poor availability/high cost of timber.

Each building model had the following unique features so the earthquake resistance characters of them could be compared.

Model 1 - No through stones or skin dog toothing. Timber lintels above the openings 150mm bearing lengths.

Model 2 - 3 Concrete hatıls cast at heights 0.9m 2.1m and 2.6m and 100x100mm section. Dog toothed masonry. precast concrete lintels with 200mm bearing lengths.

Model 3 - Dog toothing dressed quoins, three wood hatıls at 0.9m 2.1m and 2.6m. The hatıls at 2.1m on both sides of the walls are joined together by wood crosspieces. Wood lintels with 150mm bearing lengths.

The test results were as follows:

MODEL 1:
- no damage at 0.6g, 1 cycle
- loosing of mortar 0.6g
- development of crack west wall 0.75 to 1.0g
- large bulge north wall 1.0g
- skin collapse of east wall 1.1g
- west wall collapse 1.5g

Model 2:
- no damage .05g, 2 cycles
- loose mortar and little wall north and south bulging 0.5g
- loosening of corners and wall deformation 0.85g
- large deformation north and south walls cracks in ring beam 0.9g
- major cracking of in plane walls 0.9g
- internal wall collapse 1.6g
- north wall corner unstable 1.6g
- stone loss north and south walls 1.6g

MODEL 3:
- no damage 0.6g, 3 cycles
- south wall bulging below lintel roof swaying 1.0g
- hairline cracks south wall, 10mm cracks north and south walls 1.05g
- widening of existing cracks, small stone dislodgement, local collapse south wall below lintel 1.60g
- widening of cracks in all wall 1.65g
- further collapse south wall, bulging in north and south wall 1.75g
- stone collapse, lintels and roof remain supported 2.02g
- major stone loss all walls 2.04g
- loss of stone from north and south walls 2.06g
- few surviving structural element 2.1g+

Discussion of shaking tables results

The damage character of all three models was visually very similar to that seen in earthquakes - excepting that there wereea no motions in two of the axial directions and that the table did not model shear-waves. However, a group of internationally renowned seismic engineers, who were to begin with very sceptical about the shaking table simplicity, were later enthusiastic about the results. The table works on one parameter and therefore motion input and output do not introduce complexities which require vast amounts of time - instrumentation - money to understand.

In reality, the motion in one direction only, was greater than experienced in real life. As the walls were new they performed better than would be typically expected for old and decayed walls

In the unreinforced wall there was total failure - evidenced in the out of plane motion walls - normal to the motion - where maximum damage was high up and mid span and in the non roof load bearing elements. In the reinforced walls the major deformation was experienced mostly in the in plane walls - those acting in shear and parallel to the motion. Here, the roof load tied to the top ring beam may have contributed to the lateral inertia

The two reinforced structures behaved in a comparable way - short length cracks followed by stone detachment/progressive failure. Here, the ties stopped whole walls from toppling. In the timber hatıl model the main failure was through the disintegration of the stone work whereas in the concrete hatıl model the failure was in the beams themselves. The timber perhaps proved more ductile whereas the concrete showed brittle failure.

Greatest resistance in the models was at points where the masonry was well detailed. Corner quoins, dog-toothing and through stones all helped to resist skin splitting etc. The use of cement mortars could considerably helped in this respect.

The longer the door and window lintels the better, as they helped in resisting the opening distortion.

The shaking table experiments described above go a considerable way to defining the way that a new traditional building would behave in an earthquake. The principle shortcomings of the work lie in the fact the structures are new and the table induces a one directional motion. However, the model work appears to be accurate in showing relative vulnerability - the performance of various modified structures when examined against each other and a typical copy of traditional one with no such improvements.

5. Conclusions

Systematic field observations in earthquakes, even when the sample is large and the buildings have many common traits, show many complex 'sets' of damage. Combinations of failure that are only seen after the event or at one location or are not yet understood, due to the difficulty of recovery of masked failure progression.

The model work is perhaps the only economical and practical tool for then seeing how to reduce vulnerability. It could be many years before a real earthquake tests a set of structures with improved earthquake resisting techniques. The theory of improvement, by experts, hardly ever accurately lives up to expectations!

The work supports the view that at such times when there were no professional engineers the builders were quite capable of significantly improving structural performance with complex integration of different materials to form a hybrid structure.

It is clear that the progressive addition of stronger and more durable building materials into a wall aids in its ability to withstand earthquake motions. However, this correspondingly requires more money, time, and maintenance effort. Such interventions are often not socially acceptable (not conforming to tradition and uniformity), are not financially feasible, and are not technically possible. For such reasons the use of manuals and even short term training sessions are not always successful. Seismic upgrading an area, rather than an individual structure and to the point where damage and injury statistics are noticeably changed, requires external funding and a long-term commitment. For such reasons the role of aid agencies in providing anything but short-term aid is questionable.

As a result of the work in Yemen and Erzurum earthquakes, it was clear that most disaster recovery typically takes place by the inhabitants themselves. Despite international and national aid and technical help from NGO's, the majority of new buildings follow the existing types. Building are recovered in a mixed sort of way and responding to personal and local group priorities:

- Some people simply reoccupy the damaged structure and do not attempt repair or improvements.

- Slightly to moderately damaged buildings are patched or repaired on the cheap so they are quickly reoccupied - they tend always to be in a weakened state.

- Moderately damaged buildings are substantially repaired as they are seen as the central tying element of the family structure (the English mans home is his castle) and the family owns no land elsewhere. Here, the structure may be substantially improved and rely only partially on incorporating original elements.

- Moderately to severely damaged buildings are robbed of materials for reuse in new traditional styled structures.

- Some inhabitants delay rebuilding and either initiate new sorts of structures or wait until aid brings new building materials. forms/technical aid.
- New settlements spring up often on new sites of an inferior quality (e.g. poor soils - liable to flooding - wind traps etc.).

These findings indicate there are many opportunities to technically improve the earthquake strength of traditional damaged structures. The damage mechanisms suggest a sequence of priorities to the many interventions - and the order below represents one approach where the emphasis is on saving life then the structure and to a condition where some or all of it has a reuse possibility:

1) Better placing of stones to resist stone dislodgement.
a) longer stones.
b) more staggered joints.
c) through stones.
d) reduction of small core stones.
e) complete bedding of stone and with thin mortar beds.
f) buttressing of wall in similar wall building technique.
g) smaller openings and more regular form to structure.

2) Better detailing of stone at the corner to withstand wall to wall separation
a) long quoins.
b) corner reinforcement with wood or concrete beams.
c) corner stone columns.
d) incorporation of metal bars or mesh.

3) Roof improvements
a) longer beam embedment in to walls.
b) beam detailing to stop decay/infestation.
c) tying of beams to wall plate/ring beam.
d) making roof monolithic.
e) connection of roof to ground on a load system independent of walls.
f) lighter roofs.
g) uniform load transfer on to all external walls.

4) Wall strengthening
a) replacement or rubble masonry with worked ashlar.
b) cement type mortars.
c) ring beams at several levels.
d) regular vertical posts for load transfer.
e) systematic vertical reinforcement.

There is an increasing cost from 1 to 4 above. It is clear that there are many actions that can be done at little cost - reflecting on just the need for better awareness and attention to detail. The addition of hatıls, traditionally in wood or in concrete equivalent, is an expensive undertaking and not an exercise easily undertaken as part of a repair strategy. It can also be strongly argued that applying the above, to a repair scenario, results in a structure with a mixed/complex performance and where there could be increased damage the next time around.

For a new building, of an acceptable character to the local traditions, then interventions with the more expensive methods are viable - and hatıls systems become a technical possibility. The shaking table experiments show, for houses in eastern Turkey, the following progressive costs for addition horizontal reinforcement:

- Adding of triple hatıl = 5.3%.
- Use of cement mortar instead of mud = 6%.
- Adding of double reinforced concrete ring beam and foundation = 10%.
- Better construction detailing without the above improvements, e.g. better stone, quoins, roof cover = 20%.

It is possible to selectively introduce the above traditional improvement techniques for social and technical requirements matched to the local earthquake hazard. Selective improvements can then make a significant reduction to risk, at an economically affordable input. The techniques can also be applied in such a way as not to affect the heritage value of buildings.