Structural Analysis of Historical Constructions, New Delhi 2006
P.B. Lourenço, P. Roca, C. Modena, S. Agrawal (Eds.)

An Evaluation on Post Disaster and Timber Framed Houses by Macro Approach Based Assessment

Sinan Akarsu
Zonguldak Karaelmas University, Dept. of Architecture, Safranbolu, Türkiye

Neriman Ş. Güçhan
Middle East Technical University, Dept. of Architecture, Ankara, Türkiye

ABSTRACT: In earthquake prone rural areas in Turkey, the traditional /vernacular timber-framed (TTF) houses have been sacrificed and replaced by the un-reinforced perforated brick masonry (URPM) houses built according to the post-disaster regulations. However, building URPM houses as an alternative to TTF houses to get a better seismic performance is still a questionable issue.

This paper aims to make an assessment in non-linear behaviour of an URPM post disaster house and a TTF house in Orta town, subjected to an earthquake in 2000, by inelastic analytical procedure (pushover analysis) to estimate the seismic response of both buildings. As conclusion, a comparison is made in terms of base shear capacity, ultimate displacement capacity and approximate energy dissipation rate by using the capacity curve. In the long range, the objective is to promote the development of the processes in engineering discipline, for the conservation of TTF houses, a part of Turkey's cultural heritage.

1 INTRODUCTION

Vernacular buildings, consistent with their surroundings, were originated by the basic needs of human being. Then, they have been shaped by cultural, social and economical aspects and traditionally perpetuated from generation to generation for centuries. Today, survivors of these structures, defined as the "cultural heritage" as the examples of the traditional construction techniques, conserved and restored successfully, present the identity of the local environments where they were constructed. Unfortunately, the traditional houses are presently under a serious threat in Turkey due to the "modern" needs and demands of the community and the policies developed by the state in construction industry.

Like many developing countries, the planning and the conservation areas in Turkey developed as separate processes and even opposite to each other. In addition, the issue of conservation of historical traditional buildings has been ignored for a long time due to lack of policies. New developments in construction market entailed an increase in pressure over the traditional fabric in the historic urban sites due to the fast rate of urbanization, especially after 1960's, and resulted in transformation of the fabric very rapidly. During this process, historical traditional buildings were damaged in a large scale and new construction techniques became common and wide spread in use. While reinforced concrete masses spread out all over the country, vernacular buildings were no longer used, thus forgotten.

Among these new construction techniques, in use of reinforced concrete construction techniques wide spread, the regulations and standards brought by the state became more effective than the demands coming from public. Studies related with contemporary engineering and construction techniques were encouraged and supported where the knowledge in traditional construction techniques were still limited and insufficient. While this process took place at a fast rate in big cities, the traditional techniques were able to survive in rural areas in spite of decrease in use of the techniques and preserved their vernacular characteristics in some rural settlements. The city of Orta located in the Central Anatolia, and villages surrounding it, are settlements where the vernacular buildings mainly built in 1940's and still in use exist dominantly.

On 6th of June 2000, central Anatolia was shaken by an earthquake measured 5.9 in Richter scale. The epicentre of the quake in the North Anatolian Fault Line was on the rural area of Cankiri province. Namely Orta, the earthquake damaged 4842 buildings in different degrees where the majority of the buildings were built in vernacular construction techniques (Koçyiğit et. al, 2001). According to the reports prepared after the earthquake and the observations, it can be mentioned that the TTF vernacular houses, properly built, performed very well during the earthquake. The common damage types observed on these buildings were insignificant diagonal cracks in the stone bearing walls and in the plaster of timber framed systems, local failures in infill masonry and in roof systems. On the contrary there are some residential buildings, accompanied with high level of damage and collapse, had long been unoccupied and the structural timber members were heavily deteriorated prior to the earthquake. Mentioning the houses having timber framed structural system, it is obvious that those where the structural members are good in shape and not rotted quite a lot, all indicated evidence of the earthquake movements.

Unlike residential buildings, most of the damage was observed at the secondary structures, used as barns and storages due to lack of adequate structural system. It is observed that the secondary structures, constructed of heavy wall rubble stone with horizontal lintels "*hatıls*" and some timber post imbedded into the walls on the corners, have insufficient confinement and strength in terms of structural systems. Due to lack of sufficient confinement, the out-of-plane response of un-reinforced masonry walls to seismic loading primarily took place by cracking and instability rather than material failure in some examples (Akarsu, 2004).

In spite of the good seismic performance of these buildings, at the end of the official examinations, financial aids were granted to the majority of the owners, who have vernacular/ traditional TTF houses, in order to build "an earthquake resistant house". According to the surveys done two years after the earthquake, it is noticed that 120 households in Çerkeş, 906 households in Orta, 221 households in Şabanözü villages were selected to take grants from the state and the construction of single storey houses were started according to a standardized project (Akarsu, 2004). In the arduous conditions after the earthquake, during this rapid construction process, several problems were developed resulting either due to the troubles related with the standardized project or the difficulties in application in the local conditions. Because, the vernacular construction, called as non-engineered construction, is still not relied on unlike reinforced concrete and masonry types of construction in the government side. Considerable amount of funds have been spent for demolishing the traditional houses and building brick perforated masonry houses instead of seismic retrofitting and rehabilitation of vernacular structures.

When the TTF buildings in the area are examined, it can be stated that these buildings are the continuation of "timber-framed (namely *hımış* in Turkish) Ottoman house tradition, which was developed at the second half of the 16th century. The *hımış* building tradition firstly emerged in Istanbul then spread to Anatolia, afterwards all over the Ottoman land it continued up to the beginnings of the 20th century. After the huge 1510 earthquake, the rebuilding of Istanbul with timber by the building masters brought from the Anatolia and Rumelia is stated in historic sources (Arel, 1982:70). Although it can be observed that the earthquake fear was forgotten from time to time and the fear of frequent fires took its place in Istanbul and building in masonry was encouraged or even forced; the timber-framed (*hımış)* building tradition, continued over 300 years because of the repeatedly occurring earthquakes and availability of the local materials in Anatolia (Refik, 1988a,b, Ist Building Regulations, 1848; Building Act, 1882).

The reports prepared after the 1894 earthquake in Istanbul mention how heavy were the damages in masonry buildings. Moreover D. Eginitis, the director of the Observatory of Athens who thoroughly examined the damage in Istanbul and reported his observations to Sultan Abdülhamid II, confirmed the fact that the buildings of the 19th century urban fabric of Istanbul were mostly of timber-frame constructions and remarked with astonishment that the timber-frame constructions were more resistant to earthquakes and this decreased the life losses (Öztin, 1994: 32-38).

Similar results were reported in the following years and finally after 1999 Marmara earthquake by different authors (Şahin Güçhan, 2005, Tobriner, 2000: 76). Considering these studies, researching Ottoman hımış house tradition becomes important from several aspects:

1. The houses built in Ottoman tradition have strong earthquake resistance. Hence, great benefits can be derived for engineering discipline by researching their features.
2. The traditional houses form a majority in Turkey's cultural heritage and their protection is a legal obligation. Hence, to preserve these buildings by knowing and keeping their original features are the responsibility of the engineers and the conservation architects.
3. The vernacular houses as a continuation of Ottoman tradition representing the vernacular features form an important majority within the existing building stock in Turkey. Hence, their preservation is a rational choice for a country like Turkey having scarce sources.

When the problem perceived in this context, it becomes necessary that some engineering work should be carried out to repair the structural system and to improve the energy dissipation capacity of the vernacular structures. Intending to fill such a gap, this paper aims to observe the difference in behaviour patterns and to make a comparative evaluation of the traditional /vernacular timber-framed (TTF) houses and the un-reinforced perforated brick masonry (URPM) post disaster houses.

2 COMPARATIVE EVALUATION OF TTF AND URPM POST DISASTER HOUSES

Prior to make a comparison between the timber-framed traditional and post disaster masonry houses, it would be useful to point out some important characteristics of Ottoman *hımış* /TTF house tradition and post disaster masonry houses (URPM).

2.1 Timber framed traditional buildings

Despite some local variations depending on the local features, *hımış* buildings are timber-framed, hybrid constructions consisting of three main sections: 1. Masonry base, 2.Timber-frame section, 3. Timber roof (Şahin, 1995). Masonry base is composed of the ground floor and the foundations. The lower section up to the ground floor level is always made up of stone, while the upper sections can be constructed by the use of stone or mud brick, bound with mud or lime mortar. The walls in this section are always strengthened against lateral loads by the horizontal beams regularly embedded in masonry walls.

Timber-frame section consists of floors located on the masonry base. The wall / floor girders, main posts on the external corners of the spaces and the braces combining them form the main structural structure in this section. The most important elements between these are definitely the braces. Braces are also used in North European countries where the timber building tradition is common, i.e. Norway, United Kingdom, Germany etc. However in these traditions the timber elements are always fastened together by joints. In Japan where there is a long-standing timber building tradition, joints are accustomed while braces are not. On the other hand in Ottoman tradition, while making joints is a common practice, they are not utilized in connection of main timber structural elements. All joining is made by nails in Ottoman *hımış* houses. The use of braces combining the main posts located on the corners and the nails are the features increasing the earthquake resistance of Ottoman TTF houses (Şahin Güçhan, 2005). While the building is strengthened against lateral loads by the braces, its elasticity is increased by the nails (Popovski et al. 1999). Beside the use of stone, mud brick and / timber as infill material, another common technique is cladding the timber-framed walls in *bağdadi* (the local name for timber lath and plaster). This technique, both used in internal division walls and / or in cladding of external walls, is another feature increasing earthquake resistance of Ottoman *hımış* houses (Şahin Güçhan, 2005). As a matter of fact while the stone, mud brick, brick infill cause damage in the buildings as they are too heavy, no serious damage can be seen in the walls where bağdadi technique is used.

In early examples of Ottoman *hımış* houses, one or two external walls of the buildings are made of stone and/or mud brick masonry up the roof level. This wall called as "service wall" in traditional housing literature, includes the fireplaces, cupboards and chimneys. In the researches made on earthquake damages on timber-framed buildings, it has been noticed that the chimneys and service walls are the most damaged ones beside the masonry walls of the ground floors (Şahin Güçhan, 2005). In the roof part designed according to the form of the building, all connections are made by nails. In construction of a *hımış* house, after completion of the timber-framed section and the roof, the finishing works starts.

2.2 Masonry buildings

Masonry is one of the oldest and common construction techniques, which was used for all kind of structures. In spite of its advantages, e.g. sufficient compressive strength, low construction costs, ease of supply, no qualified workmanship, un-reinforced masonry (URM) has a crucial disadvantage in terms of seismic resistance that its low tensile and flexural tensile strength may cause cracking and reduce stiffness and strength.

In order to compensate deficiencies of URM, the lateral and vertical reinforcements in masonry are used to improve its load bearing and displacement capacity. In this study, 35% perforated clay brick masonry house, the prevalent masonry house type by General Directorate of Emergency Management Agency in post disaster housing in rural regions in Turkey, does not have horizontal and vertical reinforcement with tie-columns.

2.3 Analysis procedure

The analytical section of this paper is carried out to have better perception and evaluation of the non-linear seismic resistance of existing TTF buildings and URPM buildings. Three-dimensional non-linear static pushover analysis, capable to give more precise prediction of demands of a structure than the one in linear methods, is one of the best reasonable approach to evaluate strength of the structure in reality. In order to get overall idea about the seismic behaviour of the structure, this system has significant advantages with respect to linear analysis (Lourenço, 2002). In the non-linear static pushover analysis, equivalent frame system is chosen to analyze the structure. As known from previous studies, macro-modelling has superiorities like ease of use and requirement of small amount of resources in terms of money, time and memory. The crucial point to choose macro modelling is that this modelling is preferable due to getting more realistic overall failure pattern of the structure while micro-modelling, such as non-linear FE approach, results in better understanding about the local behaviour of the structure.

In definition of the plastic hinges, FEMA-273 and FEMA-306 documents are adopted by modelling and analysis procedures. As a tool, SAP2000 Nonlinear is employed to perform nonlinear static pushover analysis of both structures.

Analysis part consists of two parts: In the first part, the one storey URPM post disaster house newly built in Orta town after the earthquake is taken into account and then the structural system of an existing TTF vernacular house in Orta town is modelled as shown in Figs. 1 and 2.

2.4 Analytical modelling of URPM post house

In the previous studies, simplified models were commonly used to model an entire building or a part of structural system in 2D as an effective and practical macro models (Tena-Colunga 1992). Three-dimensional mathematical models are generally used for analysis of structures with plan irregularities and flexible diaphragms. In order to get better match between two analysis cases, 3D non-linear one story mechanism model is proposed with regular plan and rigid diaphragm in the modelling of the URPM house. The roof floor is considered as rigid diaphragm due to use of cast-in-place concrete instead of flexible wood framing.

While making choice on the relationship, strong spandrel-weak pier and strong pier-weak spandrel, the existing geometry of the URPM structure is taken into consideration because the presence of openings like doors and windows in the structure reduces the resistance of the piers. The strong pier-weak spandrel model provides better results for reinforced concrete shear walls, where as, underestimates the behaviour of URM walls (Bruneau, 1994).

In order to monitor the global behaviour and distribution of hinges in the structure, macro elements are constructed and analyzed by non-linear static pushover analysis method in SAP2000 software. It is clearly accepted that non-linear analysis is one of the best method, to examine all phases of overall behaviour of a structure from linear elastic part to the ultimate and complete failure part. By applying Equivalent Frame Method, URPM Walls are divided into spandrels and piers. The regions remaining in the intersection of piers and spandrels are taken as rigid zones. The nonlinear behaviour is represented by defining and assigning plastic hinges at various locations.

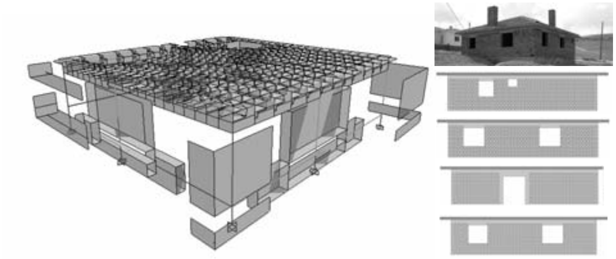

Figure 1 : Geometry of model of URPM house

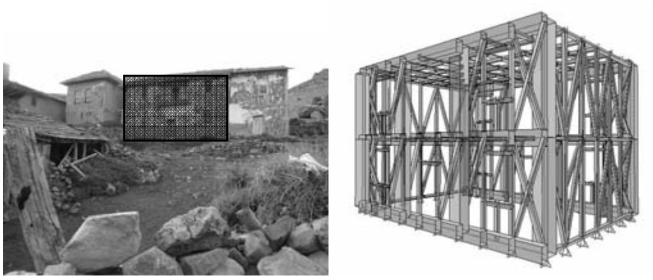

Figure 2 : Geometry of model of TTF house

In order to monitor the global behaviour and distribution of hinges in the structure, macro elements are constructed and analyzed by non-linear static pushover analysis method in SAP2000 software. It is clearly accepted that non-linear analysis is one of the best method, to examine all phases of overall behaviour of a structure from linear elastic part to the ultimate and complete failure part. By applying Equivalent Frame Method, URPM Walls are divided into spandrels and piers. The regions remaining in the intersection of piers and spandrels are taken as rigid zones. The nonlinear behaviour is represented by defining and assigning plastic hinges at various locations.

Geometry: First, a one storey, fixed at the base URPM wall, is divided into components as spandrels and piers. Then, pier elements are considered and modelled as beam-columns while spandrels are taken into account as beam elements only. Composite cross sections, such as L shape, in piers at the corners are selected to include flange effects and to make a more realistic prediction in behaviour. Therefore, the URPM walls are assumed to maintain the right angles at the corners where no separation takes place. The dimensions of cross-section of the URPM building are 8.75 x 8.55 x 2.4 m^3. In the construction of the URPM walls, 35% perforated clay masonry (PCM) bricks in accordance with TS705 are used. Dimensions of PCM unit are 0.29 x 0.19 x 0.135 m^3. URPM walls are confined at the top by partially reinforced concrete tie beams, 0.25 m in depth and 0.29 m in width. A cast-in-place concrete slab, 0.2 m thick and having 0.65m projection on the each side of the URPM walls, lies on the top of the tie beams.

Mechanical and material characteristics: According to macro modelling procedure, the clay masonry units and mortar joints are assumed to be constituents of URPM unit in an isotropic and homogeneous fashion. The material properties of URPM and RC macro-elements are based on experimental measurements from Turkish Standard Code. The material of PCM unit is assumed as isotropic with 1200 kg/m^3 of unit mass. According to TS705, the average compressive strength of PCM units is taken as 9.8 MPa. The compressive strength of the mortar is assumed as 3 MPa for mixture rate of 1:1:6 where x, y and z are the volume proportions of Portland cement, lime and sand, respectively. According to Euro Code 6, the mean compressive strength of the URPM unit is calculated as 3.83 MPa with 0.17 of Poisson's ratio. For short beam columns like in our case non-linear material model and rigid plastic material model produce very similar (Hansen, 2003). Therefore, for simplicity to get closed form solution of moment and axial load capacity relationships, the ultimate moment function of axial load is computed on the basis of rigid plastic material. For adequacy of the rigid plastic model, a zero tensile stress is assumed.

Finally, the initial modulus of elasticity and cracked modulus of elasticity values for URPM are computed as 3191Mpa and 1920 MPa respectively.

Modelling: First of all, a computer model, having three-dimensional assemblies of structural components is set to represent the structural system of URPM house. URPM piers are assumed to be perfectly fixed at the ground level. For simplicity of the analysis, some assumptions are made like rigid connection between Masonry spandrels and piers. Therefore, the regions remaining in the intersection of piers and spandrels are modelled by defining end offset along length and rigid zone factor.

Definition of the interaction between structural components of URPM structure plays an important role in modelling. As considering the rigid roof diaphragm in URPM unit, tie beams and proper ties between URPM out-of-plane walls, URPM in-plane-walls, tie beams and the floor, the most critical components in the event of complete collapse will be the in-plane-walls proven by experimental researches and post earthquake observations. The relationship of strong spandrel-weak pier assumes that piers are main structural members subjected to damage where as spandrel beams remain undamaged. Therefore, when the strength capacity of all piers or some of them is exceeded, the collapse of the structure takes place. According to the geometry of the URPM house in general, use of strong spandrel-weak pier relationship seems to be more reasonable, but non-linearity is assigned to both piers and spandrels, in order to get more realistic approach.

Properties and acceptance criteria of all hinges for URPM piers, RC piers, URPM spandrels and RC tie beams are respectively defined by aforementioned FEMA codes. While making decision on type of hinges, the structural components are taken into consideration. For example, the P-M2-M3 hinge is appropriately set for RC posts where biaxial loading takes place. On the other hand, URPM piers are modelled with combination of P-M2-M3 hinge and shear hinge. As for URPM spandrels, they are adopted as deep beams and combination of moment hinge and shear hinge is taken into account. Finally, RC tie beams use the moment hinge. Then, the moment and PMM hinges are assigned at the ends of structural elements whereas shear hinge is supposed to be on their mid-length. While plastic deformations on structural member develop in the hinges, the rest of the member undergoes in elastic fashion. It is noted that the computer program used in the analyses is a 3-D program in which the response of reinforced concrete beams and columns were idealized by elasto-plastic moment-curvature relationships. Load cases, such as Gravity, Lateral_pX, Lateral_nX, Lateral_pY and Lateral_nY, are determined as pushover load cases. "p and n" in load cases represent positive and negative directions respectively. In order to include the effect of asymmetry in planes, perpendicular to the applied lateral loads, the lateral loads are applied in both positive and negative directions. While applying the lateral loads as a fixed load distribution in both directions, the effects of accidental torsion are included by offsetting the centre of mass 5 percent of the corresponding dimension at the roof level. The gravity load is applied as the first case and then succeeding lateral pushover load cases in x and y directions are defined as extension of gravity pushover. In addition, in both analyses, gravity load pushover is taken as force controlled while lateral pushovers are selected as displacement controlled. While determining target displacements of both analysis cases, the structure is assumed to experience with overall collapse to predict the ultimate capacity. Node located at the mass centre of the roof floor is determined as control node to make comparison in target displacement. Target displacement is selected big enough that collapse of the building is observed before exceeding the target displacement.

2.5 Analytical modelling of TTF house

In general, non-linear static analysis fails to predict the higher mode response of flexible structures. When the TTF house is considered in terms of the number of storeys and vertical regularity, the static procedure is expected to be relevant to get realistic behaviour. 3D non-linear two story mechanism model is used with regular plan and flexible diaphragm in the modelling of the TTF house. The roof floor is considered as flexible diaphragm due to use of flexible wood framing. The nonlinear behavior is represented by defining and assigning plastic hinges at various locations in timber frame and infill struts.

Geometry and Modelling: First, geometry of a cut stone infilled timber frame is formed. Nine bays and two story timber frame, simply supported at the base, is modeled with total height of

5.6 meter and total width of 6.3 meters. All wooden studs, cross-beams and braces are in 0.1 by 0.1 meters in cross-section. Wooden PMM and M3 hinges are assigned to posts and beam-ends respectively. It is noted that the computer program used in the analyses is a 3-D program in which the response of wooden cross-beams and studs were idealized by elasto-plastic moment-curvature relationships. For this purpose, timber studs, cross beams and braces dividing the infill into the infill panels, are employed. Cross beams are modeled with real hinges at the ends.

The approach proposed in FEMA-356 is employed for the determination of the equivalent width of the infill. According to this approach, the infill walls are modeled as compression. The material properties of frame and infill macro-elements are based on experimental measurements from Turkish Standard Code. PMM hinges are placed at the ends of the timber studs. To determine the PMM hinge properties and the stress-strain relation of the Slyvestris Pinus type of wood, couples of four point bending test were conducted. As a result of this test, moment curvature and stress-strain relationship is derived according to Langenbach et al. (2006).

3 CONCLUSIONS

The non-linear seismic response of an URPM post disaster house and a TTF house in Orta town were investigated to make an assessment on their seismic performance. Both of them are pushed until they become unstable and reach their collapse state by using nonlinear static analysis procedure. The base shear versus top displacement relationships, commonly referred to as the capacity curve, for both cases are plotted to make comparison in terms of seismic performance that these curves result in an overall summary of the capacity of the structures. After that, values on the initial elastic stiffness, the ultimate strength and the ultimate displacement are inferred from the capacity curve and tabulated in Table 1. In addition, the damage pattern of the building at any post-yield level is monitored by examining response parameters like hinge locations.

Table 1: Comparison of mechanical properties of URPM and TTF houses

	Initial Stiffness kN/m	Strength kN	Ultimate Displacement Capacity m
URPM House	54138	924	0.05891
TTF House	38229	318	0.148339

As seen from the table, URPM House initially behaves 42 percent stiffer than TTF house. In addition, ultimate strength capacity of URPM house is approximately 2.9 times larger than the one in TTF house. On the other hand, the displacement capacity of TTF house indicates that the energy dissipation capacity, area under the pushover curves shown below in Fig. 3, of TTF house is considerable bigger than the one in URPM house. On the other words, the energy dissipation capacity, crucial factor for seismic resistance, has been significantly improved in TTF house as seen from area under the pushover curves shown below in Fig. 3. Regarding the evaluation of the results obtained in this study, it may be concluded that TTF buildings, allowing the structure to dissipate seismic energy by controlling the inelastic behaviour, possess low stiffness and large inelastic deformation capacity. However, URPM systems possess high stiffness, which leads to high seismic force demands; and small deformation capacity.

On the other hand, the pushover analysis results indicate that floor flexibility is very important factor that may totally change the seismic response of the buildings. Torsion effects are reduced significantly as the flexibility of the diaphragm is increased. Therefore, the fundamental mode shape of URPM house with rigid diaphragm is longitudinal, where as the one in TTF house with flexible diaphragm is torsional.

It is believed that assumptions, made due to the difficulties in mathematical modelling of the structural elements and uncertainty in material properties, do not affect overall behaviour of the buildings. Further studies on the effects of these issues are considered to be necessary in the future. In addition, it will be necessary to perform some experimental studies to validate these pushover analyses results too.

Considering the results of the macro based inelastic assessment presented in this paper, it should be mentioned that TTF houses are quite resistant against the earthquakes; but most of their features are not well known either by the engineers or the architects. Further studies on earthquake behaviour of these houses will guide both disciplines and facilitate development of the building procedures while helping conservation of the majority of our cultural heritage that consists of TTF houses in the case of Turkey. It is expected that considerable amount of funds may be spent for seismic retrofitting and rehabilitation of vernacular traditional structures instead of demolishing them by just calling as non-engineered structures.

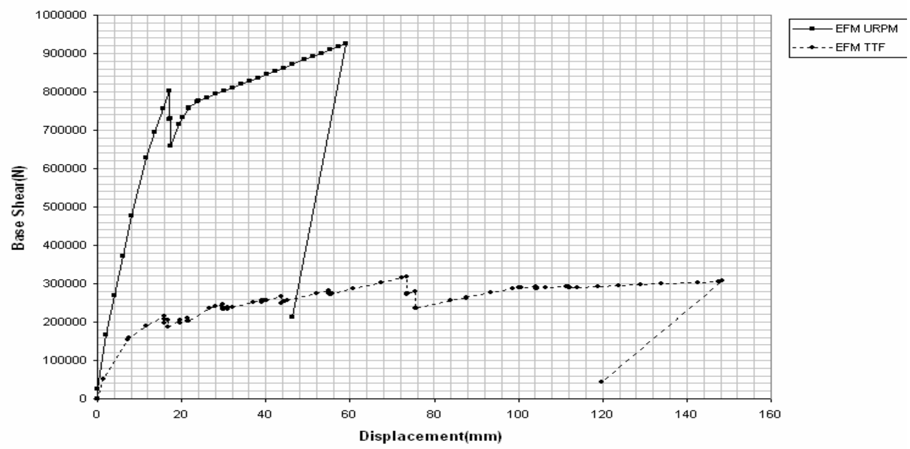

Figure 3 : The Capacity Curves for both URPM and TTF houses

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