Nonlinear Analysis of Masonry Structures

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ABSTRACT

Non-linear procedures are an effective way of linear seismic analysis. Masonry has its own credit in building industry. Masonry buildings made of brick and stone are highly durable, heat resistant and formative in nature. Since the masonry materials are easily available, this type of construction is preferred in rural, urban and hilly regions. Masonry structures fail considerably under lateral loading. The collapse of masonry structures leads to the loss of human lives and property. Nonlinear static analyses predict the force-displacement curves of masonry structures effectively. Due to the complex nonlinear behavior of masonry panels, the linear static analyses become inadequate. The choice of the appropriate model to use is of great importance as many aspects must be considered to reach a good approximation of the structural response. Nonlinear static procedures (NSPs) are the only effective alternative to traditional methods of linear seismic analyses. Such methods simulate the actual seismic behavior of individual masonry shear walls and nonlinear response of masonry buildings. In this paper a new method of predicting the seismic response of masonry buildings is presented. By means of a displacement based NSP, the torsion rotations of diaphragms are considered. Nonlinear static analyses are the most effective way to obtain the force-displacement curves of masonry structures. The choice of the appropriate model is a matter of great importance. Many points are to be considered to reach a good approximation of the structural response. Many structural models which predict masonry buildings response have been proposed in recent time. These models try to get a balance between the complexity of the model itself and the accuracy of the obtained results. Nowadays apart from other construction techniques, masonry has got its own importance in building industry. Masonry buildings of brick and stone are strong with respect to durability, fire resistance and formative effects.

Keywords: ***Earthquakes, masonry structures, Finite element, nonlinear static analysis.***

INTRODUCTION

Masonry buildings are construction of building units bonded together with mortar. They are huge structures on which large horizontal forces act during earthquakes. The earthquakes in India resulted in the loss of human life due to the inefficiency of buildings to carry seismic loads. The earthquake may be minor, moderate or strong in nature. The intensity of earthquake is directly proportional to its magnitude and the distance between the site and the source of earthquake. It also depends on the geography of the area. Some earthquakes occur in remote, undeveloped areas where damage is negligible whereas others occur in densely populated urban areas which result in significant damages to infrastructure. The earthquakes cannot be prevented but the damages caused by it can be minimized. To reduce this damage the nonlinear analysis of masonry structures is essential.

The masonry buildings are also designed to resist gravity loads only. So the assessment of such buildings is an important objective of modern structural engineering. The assessment of the buildings is possible by adopting two main approaches: Finite Element Method (FEM) approach and the equivalent frame (EQF) approach. In the first approach the masonry continuum is divided into a number of finite elements. The second method of approach is based on the concept of "equivalent frames" which is very common to structural engineers.

In order to maximize the exploitation of inelastic sources in newly designed constructions and to simulate the non-linear seismic behavior of existing structures under massive earthquakes, a number of non-linear static procedures have been discovered in the last decade as an alternative to non-linear time-history analysis.

As broadly recognized by the scientific community, the use of NSPs to assess masonry structures is at present the only process to predict their behavior under earthquake loading. Several features have to be considered to minimize uncertainties in safety verifications and to obtain a better approximation of the actual behavior of these structures.

If the masonry structure is regular in plan, the non-linear redistribution of internal forces is approximately uniform for all the shear walls. If it is not regular in plan, the inelastic redistribution of internal forces is non-uniform and can lead to dangerous conditions of damage. There should be reductions in global seismic capacity in terms of both resistance and displacement. Either the position of the shear centre or the plastic redistribution of internal forces can be calculated through non-linear analysis. Seismic capacity is much different from the one expected if torsion ally induced displacements are neglected in presence of large irregularities in plan. Masonry buildings are the most common type of constructions in Kerala. The surveys proved that such buildings are damaged in a huge manner in the past earthquakes. Recently the frequency of earthquakes in Kerala has increased.

IMPACT OF EARTHQUAKES ON MASONRY STRUCTURES

The earthquake is a violent shaking of the earth where large elastic strain energy is released in the form of seismic waves travelling along the surface of the earth. Rocks are made of elastic material and elastic strain energy is stored in them during the gigantic plate actions that occur in the earth. The material of rocks is very brittle. When the rocks along a weak region in the earth’s crust reach their strength, a sudden movement takes place releasing large elastic strain energy on the rock surface. The sudden slip at the fault causes the earthquake when large elastic strain energy released spreads out in the form of seismic waves that travel along the surface of the earth. After the end of earthquake, the process of strain build-up starts all over.

Earthquakes lead to a series of vibrations causing extra bending and shear stresses in structural walls. Sliding shear failure: It results in a building sliding off its foundation. It is caused by low vertical load and poor quality of mortar. It can also occur within the building structure.

Diagonal cracks: The tensile stresses developed in the wall under vertical and horizontal loads, exceed the tensile strength of masonry material.

Failure due to Overturning: This failure takes place under the action of overturning moments. The critical nature of the overturning effect is related with the form of buildings vertical profile.

Buildings that are squat in form do not fail in this manner while the tall, slender forms fail easily. A wall that is too tall or long in comparison to its thickness is easily exposed to shaking in the weaker direction.

Nonstructural failure: The structural elements of a building should resist forces taking place due to earthquakes. The nonstructural walls and window frames of the building should be protected against shaking actions. The failure has danger to the residents of the building and includes high expenditure due to replacements of damaged parts of the building. Interior partitions, curtain walls and other building elements are exposed to shear stresses during earthquakes for which they don’t have enough resistance capacity. The most common damage includes breakage of window panes and cracks in internal plaster.

Site failure: Five common site failures exist during earthquakes. They can cause damage to fences, retaining wall and other elements.

Foundation failure: Site failures can damage the building foundations. If the ground moves, the foundations will move. The foundation system and the ground should move together during earthquakes when supports have too many isolated column footings to allow the lateral loads to be shared among all the independent footings.

SEISMIC COEFFICIENT METHOD OF ANALYSIS OF MASONRY STRUCTURES

Seismic analysis is carried out assuming that the horizontal force is equal to the dynamic loading. This method is less laborious because the periods and shapes of higher natural modes of vibration are not required. The base shear is calculated on the basis of structure’s mass, its fundamental period of vibration and corresponding shape. The base end shear is distributed along the height of structure according to the code formula. This method is conservative for low-to-medium buildings with a regular conformation.

The total design lateral force is determined by the following expression:
$V_B = A_h$ x W.
Where
V_B = Design base shear.
A_h = Design horizontal acceleration.
T = Natural time period.
W = Seismic weight of the building.
The design horizontal seismic coefficient, Ah = ZI Sa/2Rg
Where Z = Zone factor
I = Importance factor, depending upon the functional use of structures.
Sa/g = Average response acceleration coefficient.

The importance factor is used to obtain the design seismic force depending on the functional use of the structure. Seismic zoning is the maximum severity of shaking that is anticipated in a particular region. The zone factor is defined as a factor to obtain the design spectrum depending on the existing seismic hazard in the zone in which the structure is located.

Response Reduction factor (R) is calculated depending on the existing seismic damage performance of the structure, accompanied by ductile or brittle deformations. The ratio (I/R) should not be greater than unity. The basic principle of designing a structure for strong ground motion is that the damage to the structural elements is permitted and the structure should not collapse.

The fundamental natural period is the longest time period of vibration. Since the design loading depends on the building period, the period cannot be estimated until the design is made.

CONCLUSION

Heterogeneous modeling is more accurate than homogenous modeling.Heterogenous modeling is time consuming and expensive. The intensity of stress is large near the base of wall and decreases upwards. When earthquake waves hit perpendicular to the longer side of the wall, it is more effective than when it hits parallel to the longer side of the wall. This happens due to the height to thickness ratio of the masonry wall. When the wave hits perpendicular to the longer side of the wall, height/thickness ratio increases than when it hits parallel to the longer side of it.

The proposed displacement-based incremental static procedures help to control the inelastic seismic response of a masonry building, considering the torsion rotations of diaphragms and using new distributed plastic macro-elements. Their strength and displacement capacities are calculated through N-V interaction domains and force-displacement curves. Different sources of geometrical and mechanical non-linearity are explained analytically considering the constitutive law.

The incremental iterative procedures presented in the paper are performed by using a new software program for seismic analysis of masonry buildings called “STAAD Pro.”It allows performing both linear and non-linear static analyses on both newly designed masonry buildings and existing ones. An individual masonry shear wall can be modeled and analyzed in comparison to the whole building. Safety verifications are done under gravity loads only in seismic conditions.STAAD Pro is an user-friendly software and provides effective tools to initiate the structural design and assessment of masonry buildings with due reference to the earthquake loading conditions.

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