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Seismic Analysis of Historic Stone Structure: A Review Paper

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***Abstract:** This general report is prepared from the selected 25 papers which are in the area of seismic analysis of structures. An earthquake is the result of a rapid release of strain energy storied in the earth crust that generates seismic waves. Structures are vulnerable to earthquake ground motion and damages the structures. In order to take precaution for the damage of structures due to ground motion, it is important to know the characteristics of the ground motion. The most important dynamic characteristics of earthquake are peak ground acceleration, frequency content, and duration. These characteristics play predominant rule studying the behavior of structures under the earthquake ground motion. The earthquake analysis of multistorey structure is done by linear and nonlinear methods. Response spectrum method of analysis is linear dynamic analysis. For nonlinear dynamic analysis time history method is used. In this paper, response spectrum method is used for linear analysis. For nonlinear analysis, time history method is used.*
***Keywords:** seismic analysis, time-history analysis, response spectrum analysis, E-tabs, seismic performance*

I. INTRODUCTION

The historic stone buildings in India are terribly vulnerable to lateral loads especially the buildings lying in the high seismic zones. Past world–wide earthquake experience shows that the un-reinforced stone masonry structure is more vulnerable than reinforced structure. Unreinforced masonry buildings are usually characterized by sudden and dramatic collapse. Analysing and strengthening of the old structures has always been a challenging task because of the complex geometries, deficient knowledge about the used materials, structural modifications and ageing of material. Conservation of heritage buildings is very important because it provides a sense of identity and continuity in a fast-changing world for future generations. Heritage buildings basically represent the past history and culture of a nation. They constitute together the architectural heritage of an area. With the development of computational methods, Finite Element Analysis has become the widely accepted tool for the analysis of structures. The vulnerability of the old buildings situated in the areas of high seismic activities is a matter of concern especially if the building is still being used. Non-linear analysis is emerging as a powerful tool to assess the strength of the structures under the seismic actions.

II. REVIEW OF PAPERS

Abin Jose et al. considered the past world–wide earthquake experience which shows that the un-reinforced masonry structure is more vulnerable than reinforced structure. Unreinforced masonry buildings are usually characterized by sudden and dramatic collapse. This review paper is mainly deals with the seismic analysis and design of masonry structure. To carry out the study at first, architectural drawings are prepared considering different functional, geometrical and engineering aspects. The building is located in Himalayan region of Nepal which is in high seismic zone i.e., V. The structure which is analysed and designed is single storied dressed stone masonry building with metal roof structure and CGI roof sheets. Then the building modelled in FEM-based software (SAP2000) for detailed structural analysis including all material properties, loads and its combination. The analysis results like direct stresses, bending stresses, shear stresses, tension, etc. are determined and checked against the limiting value of the material as per codal provision. The drawings are suitably adjusted to bring the building to safe level as per codal requirements.

Muhaned Abass Mohammed studied the seismic analysis of structures by e-tabs in B.S. code & I.S. code- Modelling of the selected building in ETABS Software was carried out. Retrieved time history and response spectrum of structure was prepared from the software. Two models as per the codes i.e., Indian code, British code specification were made.Calculation of push analysis seismic forces and load combinations as per IS 1893-2002, and BS 8110-1997. The models of the data are presented to evaluate stability.

Hina Gupta et al. considered the building constructed by Nawab Hamid Ali Khan of Rampur State in the year 1890 and was later named as “Pant Sadan”. After the visual inspection of the building, 3D modelling of the plan was prepared. The building was analysed for the combination of dead and imposed loads. The results of pushover and time history analysis show that the building is vulnerable during large intensity earthquake. Therefore, adequate repair and rehabilitation works are necessary to make it earthquake resistant.

Jacob Alex Kollerathu et al. analysed the structure using Equivalent frame modelling (EFM)and Non-linear finite element modelling (NLFEM) approach. In NLFEM, both material non-linearity, through stress-strain relations, and geometrical non-linearity are addressed. In EFM, structural element modelling is achieved by idealizing walls as frame structures where deformable parts are connected by un-deformable couplers (rigid nodes). For the safety assessment of strategically important structures, a conscious choice of the modelling approach is essential. The computational effort plays a significant role, but it should not be the governing factor in choosing the right modelling strategy.

Divya C. Bose et al. investigates the application of Nonlinear Seismic Analysis of masonry building using ANSYS software. Heterogeneous modelling gives more accurate results than homogenous modelling. But heterogeneous modelling is time consuming, lengthy and costly. The magnitude of the stress is large near the base of the wall and decreases towards the top of the wall. Earthquake wave hitting perpendicular to longer side of the wall is more vulnerable than that hitting parallel to the longer side of the wall. This is mainly due to the height to thickness ratio of the masonry wall. When the wave hit perpendicular to the longer side of the wall height to thickness ratio is much greater than when the wave hit parallel to the longer side of the wall.Alessandro Galasco et al. A new displacement-based algorithm for the adaptive pushover analysis of masonry walls and buildings is presented. The load pattern, in this case, is directly derived, step-by-step, by the actual deformed shape evaluated during the pushover analysis. The proposed procedure seems to be very powerful for in-plane analyses of walls, whilst it requires some corrections in order to be applied to three-dimensional masonry buildings.

Gireesh Babu investigated the seismic response of the structures under earthquake excitation expressed in the form of member forces, joint displacement, support reaction and story drift. The response is investigated for g+7 building structures by using STAAD PRO designing software. It's observed the response reduction of cases Ordinary moment resisting frame. In this case, we have taken earthquake zone 2, response factor 3 for Ordinary moment resisting frame and importance factor 1. Initially, started with the designing of simple 2-dimensional frames and manually checked the accuracy of the software with our results. Then according to the specified criteria assigned it analyses the structure and designs the members with reinforcement details for G+7 residential building RCC frames. In the earthquake resistant design of G+7 RC framed building the steel quantity increased by 1.517% to the convention concrete design. The steel quantity increased in the structure ground floor to higher floor i.e G+7 level of the structure.The Storey drift condition for considered G+7 building, the base drift=0.0 at every story. This says that the structure is safe under drift condition. Hence shear walls, braced columns are not necessary to be provided. Hence story drift condition is checked for the G+7 building.

G. Guruprasad performed a dynamic analysis of G+15 storied RC frame building with L, C & rectangular shape in plan with the help of ETABS software. Comparison has been done by considering the parameters such as story drift, story shear, support reactions, building mode, and section cut force. It has been concluded that maximum value of story shear was observed for L-shape plan than rectangular building and C- shape building. The stories drift values in X direction and Y direction increases for top to bottom story in all three cases. When earthquake load is applied in Y direction, it was found that irregular plan structure can resist more base shear than rectangular plan structure. Regular building and L-shape buildings gave good results than C-shaped buildings in all aspect

S.K. Ahirwar, S.K. Jain and M. M. Pande studied the seismic load estimation for multistorey buildings as per IS: 1893-1984 and IS: 1893- 2002 recommendations. Four multistorey RC framed buildings ranging from three storeyed to nine storeyed are considered and analyzed. The process gives a set of five individual analysis sequences for each building and the results are used to compare the seismic response viz. storey shear and base shear computed as per the two versions of seismic code. The seismic forces, computed by IS: 1893- 2002 are found to be significantly higher; the difference varies with structure properties. It is concluded that such study needs to be carried out for individual structure to predict seismic vulnerability of RC framed buildings that were designed using earlier code and due to revisions in the codal provisions may have rendered unsafe.

M. Firoj and S. K. Singh Based on the response spectra study on multi-storey irregular building, following points are concluded: The dynamic analysis must be carried out for high rise structure with vertical irregularities having height more than 40 m. As the modal mass participating factor is more than 75% in the higher mode, the considered structure is stiff for earthquake excitation. The frequency in first mode of vibration is found between 0.44 Hz to 0.57 Hz by different programs, which shows building much stiffer. The joint displacement in X- direction is found more as compared to Y and Z directions due to the fact that the earthquake motion was applied in X-direction. This shows the uplift in Y- direction and displacement in Z-direction.

Pere Roca et al. In spite of the important advances experienced by structural analysis methods, the study of masonry historical structures is still a challenging activity due to the significant difficulties encountered in the description of their complex geometry, materials, morphology (member composition and connections), and present condition, including damage and alterations.

In particular, the modelling of the mechanical behaviour of masonry is very demanding due to its fragile nature in tension and composite character at the macro-scale. A wide set of possibilities have been developed to describe masonry structures to different levels of accuracy, from rough (but useful) engineering approaches to very detailed modelling taking into account the distinct response of the individual components.

A very significant effort is undertaken at present to produce homogenization criteria allowing a better interconnection between the micro- and macro- analysis levels. Detailed methods, such as micro-models, are still requiring high computer effort and, in practice, can only be used to analyse small individual members such as solid or hollow walls. Moreover, the sophisticated methods often require complex material properties which can only be determined through costly and sophisticated laboratory experiments. In the case of the study of real buildings, such properties are not normally available and need to be indirectly estimated based on more common and available evidence. However, inadequate assumptions on these 34 properties may compromise the real gain in accuracy provided by sophisticate method and even lead to inadequate results.

With further developments in computer technology and numerical methods, the analysis of entire complex historical structures (including for instance, Gothic cathedrals) using very accurate approaches, may become possible in the near future. Further developments will make very demanding analyses, such as the non-linear time-domain dynamic one, possible even if used in combination with complex structural and material models. However, many of the difficulties mentioned, as those related to the adequate survey and description of the structure, including material features and damage, will still compromise the accuracy and realism of the numerical predictions. In this context, the judgment of the analyst is essential in order to conclude on the acceptability of the results.

Kalpak A. Zagade et al. describes the results of linear dynamic analysis on the P+12 storey structure based on concept of Response Spectrum Method. In 3D analytical model of P+12 storied building have been generated for symmetric building models and analysed using structural analysis tool Etabs. The analytical model of the building includes all important components that influence the maximum displacement, maximum story drift, story stiffness, maximum story displacement of the structure. The total 2 types of models are analysed and compared 1 with Response Spectrum Method (Fixed support condition) and 1 with Response Spectrum Method (Flexible support condition) the main parameter of the seismic analysis of structure are load carry capacity, ductility, stiffness, damping and mass. The various response parameter like maximum story drift, story stiffness, maximum story displacement and the maximum displacement of the structure etc are calculated.

Peter Fajfar et al. A relatively simple nonlinear method for the seismic analysis of structures (the N2 method) is presented. It combines the pushover analysis of a multi-degree-of-freedom (MDOF) model with the response spectrum analysis of an equivalent single-degree-of-freedom (SDOF) system. The method is formulated in the acceleration - displacement format, which enables the visual interpretation of the procedure and of the relations between the basic quantities controlling the seismic response. Inelastic spectra, rather than elastic spectra with equivalent damping and period, are applied. This feature represents the major difference with respect to the capacity spectrum method. Moreover, demand quantities can be obtained without iteration. Generally, the results of the N2 method are reasonably accurate, provided that the structure oscillates predominantly in the first mode. Some additional limitations apply. In the paper, the method is described and discussed, and its basic derivations are given. The similarities and differences between the proposed method and the FEMA 273 and ATC 40 nonlinear static analysis procedures are discussed. Application of the method is illustrated by means of an example. It can be concluded that the nonlinear static procedure in FEMA 273 and the proposed simple version of the N2 method are very similar, and can yield exactly the same results if the same displacement shape and lateral load distribution are assumed. The major difference lies in the visualization provided by the N2 method. In ATC 40, the transformation from the MDOF to the SDOF system is comparable to the two other methods. However, the assumed displacement shape, which is the basic quantity in the formulae for transformation, is restricted to the elastic first mode shape. Consequently, the ATC 40 transformation is equivalent to the FEMA 273 and N2 transformations only in a special case. In N2, the assumed displacements shape and lateral force pattern are related. In this way one of the approximations present in FEMA 273 and ATC 40 is eliminated.

Padol S. et al. studied the seismic analysis of multi-storied RCC building with mass irregularity at different floor level are carried out. This paper highlights the effect of mass irregularity on different floor in RCC building with Time History Method and analysis is done by ETABS software. They concluded that whenever structure has different irregularity the effect of earthquake on structure can be minimize by providing shear wall, base isolation etc.

Patil A.S. studied nonlinear dynamic analysis of 10 storied RCC building considering different seismic intensities and also studied seismic response of such building. The building under consideration is modelled with the help of SAP 2000-15 software and 5 different time histories have been used. The result of the study shows similar variations pattern in seismic response such as base shear and storey displacements and concluded that time history is realistic method used for seismic analysis. It provides a better check to the safety of structure analysed and designed.

Dubey et al. presented design of multi-storied irregular building with 20 stories and modelled it using software STAAD-PRO for seismic zone IV in India, dynamic response of building under actual earthquake, DELINA (ALASKA)2000 have been considered. This paper highlights the comparison of Time History Method and Response Spectrum Method. The story displacement result has been obtained by using both method of dynamic analysis, and Concluded that Time History Analysis is found to be 2 to 8% higher than that of Response Spectrum Analysis in both type of building i.e., regular and irregular, for high rise building it is necessary to provide dynamic analysis because of nonlinear distribution of force. Storey displacement is found greater in THM as compared to RSM, and observed that the base shear is greater in RSM compared to THM. Thus, it can be concluded that time history analysis is economically better for designing.

Rampure et al. studied the dynamic time history analysis and response spectrum analysis of a concrete gravity dam by using STAAD-PRO. Finite element approach is used to analyse the dam and a concrete gravity dam model is prepared in STAAD-PRO to perform the time history analysis and response spectrum analysis and comparison is done between both these methods. They concluded that STAAD-PRO is most convenient and less tedious for dynamic analyses and it provides a computing environment to investigate modelling assumption and computational processes related to the static and seismic structural stability of gravity dam. It is necessary to analyse the structure by dynamic analysis of both these method for below the height of dam 100m and above the height of dam 100m.

Hawaldar et al. presented G+12 storey building model with and without infill the time history analysis used for Bhuj and Koyna earthquake function it is carried out in ETABS 2013 software. The seismic responses of story displacements, storey drifts are observed. Time history plots of base force v/s time and roof displacement v/s time for both time history functions are compared and studied. They concluded that the displacement values for Bhuj function are higher than the displacement value for koyna function and those for infill building are less than that without in filled building and drift value of Bhuj function were more in comparison with drifts for Koyna function and infill drift values are comparatively less than for without infill drift values for both time history function.

Hassaballa A.E. et al. studied the seismic analysis of a RC building, and investigate the performance of existing building if exposed to seismic loads. This building frame was analysed by Response Spectrum Method and frame is computed through STAAD Pro software. For seismic analysis of multi-storey building, they used static load and seismic load and get result that design based on response spectrum method required large dimension of to resist large displacement. And concluded that drift resulting from nodal displacement due to combination of static load and seismic loads were about 2 to 3 times the allowable drifts.

Nicola Augenti et al. The proposed displacement-based incremental static (pushover) procedures enable to control the inelastic seismic response of a masonry building, taking into account the torsional rotations of diaphragms and using new distributed plasticity macro-elements. Their strength and displacement capacities are estimated via N-V interaction domains and force-displacement curves, respectively. Different sources of geometrical and mechanical non-linearity are analytically described accounting for the adopted σ-ε constitutive law. The incremental iterative procedures presented in this paper were implemented in a new software program for seismic analysis of masonry buildings, called the "RAN code". It allows to carry out both linear and non-linear static analyses either on newly designed masonry buildings, or on existing ones. An individual masonry shear wall, rather than a whole building, can be modelled and analysed. Safety verifications are performed in separate sections under gravity loads only and in seismic conditions. RAN code is a wholly user-friendly software and gives effective tools to optimize the structural design or assessment of masonry buildings, with particular reference to the earthquake loading condition.

Saba Shamim et al. An Unreinforced Masonry Heritage school building situated at Aligarh Muslim University; Aligarh has been investigated for possible seismic failures using SAP2000 Finite Element Software. The school building being a massive and complex structure has been modelled using homogenous modelling approach. The material was considered to be homogenous and isotropic. The natural frequencies and mode shapes were computed using modal analysis. The building was then subjected to seismic ground motions in both X and Y directions to determine its seismic performance. The results showed that the building was safe under gravity loading but some weak zones were found under earthquake loading. In order to conquer the exceeding stresses a rehabilitation study has also been performed to see its effectiveness on the Heritage school building model which proved to be satisfactory.

Gaurav Kapgate et al. Structures need to have suitable earthquake resistant features to safely resist large lateral forces that are imposed on them during frequent earthquakes.

Ordinary structures for houses are usually built to safely carry their own weights. Lateral forces can produce the critical stresses in a structure, set up undesirable vibrations and, in addition, cause lateral sway of structure, which could reach a stage of discomfort to the occupants. Shear wall is one of the most commonly used lateral load resisting element in high rise building. In this study, the non-linear El-centro time history analysis is carried out for special moment resisting frame under earthquake loading using computer software E-TAB 2016. By addition of shear wall base shear is increased than in bare frame. Inner shear wall reduced large displacement in both directions than outer shear wall. Also, inner shear wall reduced peak spectral acceleration drastically than outer shear wall.

Nyein Nyein Thant et al. The present study of the proposed building is eleven-storey setback steel structure. This structure is situated in destructive zone V. The proposed building is analysed and designed with the help of ETABS 2016 software and ASCE 7-10 specifications. After RSA is done, CSA is considered with gravity loads plus lateral loads. The maximum storey displacement with CSA is increased by 56% than the displacement with RSA. The maximum axial forces values obtained for columns with CSA is increased by 48% than axial force with RSA. The maximum shear forces and bending moments with CSA are more than shear forces and bending moments with RSA. The shear force and bending moment for selected beams are significantly decreased at the level of discontinuity of the proposed building. Due to application of gradual load in CSA, loads are transferred to the lower storey. The lower floor is more sufferable than the upper floor. So, the maximum values of shear forces and bending moments of selected beams are observed at the first floor. Therefore, CSA is more effective than RSA on the setback steel structure. In this study, dead load and earthquake load control for the structural frame sections with CSA. Setbacks cause a sudden variation in earthquake forces of discontinuity. As a conclusion, CSA must consider not only multi-storey setback building but also location of building in seismic destructive zone.

S. R. Kangle based on his study on the response spectra study on multi-story regular building concluded the following points: 1. The dynamic analysis must be carried out for high rise structure with vertical regularities having height more than 40 m. 2. As the modal mass participating factor is more than 75% in the higher mode, the considered structure is stiff for earthquake excitation. 3. Response spectrum analysis was performed on the building; from this analysis it was concluded that the structure has good resistance to smaller earthquake of moderate magnitude and intensity. 4. The story displacement in X- direction is found more as compared to Y and due to the fact that the earthquake motion was applied in X-direction. 5. By the analysis results, we can find that the base reactions for the structure is coming little bit different from both the software's.

A. Krishna Srinivas et al. As compare to the high-rise building, low rise buildings (irregular) also required some special care in planning and in design to resist earthquake forces. The mass of the building that is effective during earthquake shaking. The seismic mass distribution in irregular building along the plan is different, so it is very effective in lateral oscillation during earthquake. The buildings with irregularities also showed unsatisfactory results in both direction of buildings. This proves that irregularities in buildings are harmful for the structures. From this study it is proved to prefer the plan irregularities to distribute the seismic lateral inertia force to various lateral load resisting systems in proportion to their lateral load resisting capacities.

III. SUMMARY

A proper understanding of the earthquake ground motion plays a key role in the efficient design of seismic analysis. This general report summarizes the various recent developments in research and practice in the area of seismic analysis. The subjects of these papers cover a variety of sub-themes like non-linear dynamic and linear dynamic analysis which include response spectrum and time-history analysis, modelling using E-tabs and analysis under seismic loading. Future scope of research and development of practice in thearea of seismic analysis of structures can also be obtained from the present paper.

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