Seismic Assessment of a Hospital Building: A Case Study

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Abstract

Presently, the occurrence of frequent earthquakes worldwide is becoming a noteworthy problem. Hospital buildings are one of the important structures in the living society as they aid to be the caring as well as curing unit in the human society whenever any hazardous situation arises. There are three components of a hospital building including Structural Component, Non – Structural Component and Functional Component, which directly or indirectly affects the operation and the management of the hospital building. Each time, if any portion of the world experiences any causality: Natural or Non – Natural, a good amount of damage and destruction is experienced. Hospital buildings play a dynamic role in such situations: 1. Treating the victims and injured people, and 2. Act as a temporary accommodation for those people who lost their homes in the hazards. Therefore, the hospital buildings should be designed and constructed to have adequate stiffness and strength to not only withstand the disaster, but also can be used as a shelter or accommodation units during post – disaster conditions. This study includes the analysis of a hospital building located in the North – Eastern Region of high seismicity. The existing hospital structure is analyzed for determination of the weak structural members. The analysis tool considered for determining the behaviour of hospital building when subjected to seismic forces is ETABS 2019. The analysis considered for determining the effect of the lateral forces on the hospital building is Pushover Analysis. Indian Standard Codal Provisions of IS 1893: 2016 has been considered while applying the different loading conditions on the hospital building. Later, different materials for bracing have been compared to determine the best possible material or section for the hospital building to resist the seismic forces. After the conduction of the study, it as been observed that angle section of different dimensions of the legs are found to be the most efficient section.

Keywords: Seismic Assessment, Hospital Building, Pushover Analysis, Retrofitting, Bracings

1. Introduction

According to the United Nations Office for Disaster Risk Reduction (UNISDR), a disaster may be described as "a serious disruption of the functioning of a community or society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope with using its own resources". But, due to the advancement in the technology and science, the different types of disaster can be predicted and the effect of the same can be reduced by giving proper timely warnings and precautions. It has been observed that the occurrence of the various disasters are increasing from the year 1950 to 2020. During most of the disaster, the response management lies on various different factors which include the provision of the infrastructure of hospitals, viability of roads, the team of rescue and search, department of civil protection activities, aerial medical evacuation and most importantly the installation of the hospital facilities at the fields. The component above stated of this response management depends upon the functionality of each other. Thus, it is very important that at the time of any disaster, all the components should work efficiently and effectively, by considering the effect of the other component simultaneously. Hospital systems should be designed in such a way that the can able to manage immediately a large number of casualties during and post – natural disaster. The picture of the hospitals during any disaster, especially earthquake, witnessed that the hospitals are facing a large number of casualties, which must be able to reach the destined nearby hospital within 24 hours as per the Golden Rule. Sometimes, it may be possible that the resources of the hospitals are limited. These resources may include the availability of the medicines, treatment
units, beds, etc. in such scenarios, there will be a problem faced by the hospitals during and after any natural disaster because the number of the people will definitely increase as the rescue operation speeds up in rescuing the people, they will receive more injured people and those people should have to be sent to the medical structure for their treatment to the earliest. Thus, a hospital should have a proper management in such a way that if they are facing any kind of problem of overcrowding and limitation of the resources, they must have a backup plan to get rid of this problem and perform their job in curing people. According to the references set in the framework of rules prescribed in the world recognized codal provisions for the seismic action on the existing buildings such as FEMA 356 [1], Euro Code 8: Part III [2], a process is defined for the risk mitigation strategies. The process in defining a strategy for the risk mitigation for important buildings consists of following steps:

- Examination of Typological Data of the buildings,
- Analyzing the structural vulnerability and building risk levels,
- Determination of the strengthening actions against the seismic environment and the cost analysis of the same,
- Making a plan which is used to set the priorities post – earthquake.
- Selecting an appropriate policy which results a progressive and speedy recovery.

Presently, many methodologies had been developed, modified and adopted for determining the behaviour of the hospital building under seismic scenarios. The methodologies gave the models for the analysis purpose, which may lead to some complex result and discussions. The theories which are adopted, are mostly focusing on Reliability Analysis, Leontief Model Input – Output Analysis, etc. Furthermore, apart from these mathematical concepts, several guidelines have been presented for the different nations of the world, both including developed and developing nations, on assessing natural hazards by World Health Organization (WHO) under Hyogo Framework, which is a drive for safe hospitals. As per the United Nations, Geneva and New York, preparedness may be defined as the information and the capabilities of the government, the recovery and response communities and institutions. It may also include the respond by the local people, their needs and suggestions for the recovery process from any disaster. In context to the healthcare structures, the preparedness refers to the different measures and actions adopted by the stakeholders of the hospitals in reference to plan, organize, giving proper knowledge teaching, preparing, exercising, estimating and considering remedial actions to construct, minimize the disaster impact and safeguard affective management during event reaction. Table No.1 shows the instrument for assessing the preparedness of present hospitals, which are executed by global organizations, considering 3 chief components: Structural, Non – Structural and Functional. The Centre for Earthquake Engineering Research (MCEER) R4 defines a resilience agenda which provides various steps that are helpful in the upgrading the resilience for hospital structures, infrastructural arrangements, etc. This R4 agenda consists of 4 indicators: 1. Redundancy, 2. Rapidity, 3. Robustness, 4. Resourcefulness. These agendas must be used for the evaluation of the potential measures of the hospital buildings such as its safety against disasters, preparedness for any unfortunate situations, continuous availability of the healthcare services, and the ability to adapt and response in any disaster condition. The MCEER also distinguish into 4 areas: 1. Organizational, 2. Economic, 3. Technical and 4. Social. The technical and organizational domains are of most importance. The technical area mainly related to the physical properties of the systems, which focus on the capability to resist destruction and any failure in the functioning of the hospital building. The organizational area only has its attention on the management of the hospital’s physical attributes.

1.1. Role of Hospitals and its preparedness against earthquake

After earthquake occurs, hospital plays the critical role of treating any kind of casualties. In most of the cases, the key parts of a hospital which includes the building itself, staff, technical systems, and medical equipment are affected by the earthquake. To handle the demand caused, affected hospitals should recover in an effective and efficient manner. The recovery of a hospital is a dynamic and complex process as every component requires specific types and amount of time and resources to recover. Also, the recuperation of each component just not only affects its performance but also plays a major role in the recovery of the overall hospital. Hospital structure need to be model in such a way that it can resist the earthquake forces which are coming on the structure. Also, if some of the components of the hospital got damaged, its recovery should be done in the minimum time possible. In order to design and analyze the model of a hospital for its preparedness against the natural disaster such as earthquake, numerical Finite Element Analysis (FEA) is considered a reliable tool for response assessment of structure under extreme various loading
conditions. When the models are developed in the software, various geometrical assumptions may typically be taken into consideration to simplify the modelling way of approach. The consequences of considering these assumptions on the analysis, could be substantial and may alter significantly the result focused on the design, assessment. Another option is to retrofitting of the structure. The significance of the accurate modelling of the structure is a must for post-disaster recovery management, followed by a supreme event. When earthquake is hitting a place, it is always recommended to carry out a simple, fast and reliable vulnerability estimation of seismic events in order to cope up the emergency in the most efficient way and reach at the most efficient hospital response. The approaches which can be considered to get the desired results adopt a methodology which is not only based on structural parameters but also, consists of a mixture of certain research-based approaches (Leontief Model; A study with the data collection in the field using the World Health Organization (WHO) evaluation forms). In European nations, according to European Commission's Framework Program 7, a project: MOVE - Methods for the Improvement of Vulnerability Assessment in Europe, has been used to define the methodology for the preparedness of the hospitals for natural disasters such as earthquakes. This methodology had been applied mostly in the Florence region of Italy. It had been observed that by little modifications in the data, this methodology can be applied to any other European nation. Also, to apply this methodology in the other parts of the world, the data in the software used in this methodology is changed according to the location of the hospitals.

For example, The Oral and Dental Hospital of General Soedirman University, Java Islands, Indonesia is 4 stories building, which is expected to serve an important function as a public facility, due to which the building is having a higher level of security when the country faces an earthquake. The evaluation is done by using a Rapid Visual Screening method and a Tier 1 Evaluation using FEMA 310 [3]. On majorly basis, every study consists of 3 sets of methodology and their respective checklists which allow a speedy assessment of the structural, non-structural and foundation/geologic elements of a particular structure and site conditions. A hospital has several independent components, which actually defines the levels and the services offered by the hospital. The components, as already stated includes staff people, medical facilities, etc. After the hospital building is subjected to earthquake forces, maximum available resources must be used in such a way that the hospital’s functionality should be come on the track to the earliest so that it can be able to treat the victims of the natural hazard. As it can be easily understood that the end point of the entire rescue chain is the hospital infrastructure, which is not only one of the most important elements of medical response to earthquakes, but also provides shelters that lost their homes during earthquake. Therefore, it is necessary to carry out a simple, rapid and reliable risk assessment of the impact of natural disaster on hospital structure. The hospital structure is considered to be as one of the most important structure and they must be given importance while designing as if they are designed effectively, they can resist the impact of any natural disaster. Each and every component of the hospital should be designed in such a way that they can able to withstand the vertical as well as the lateral force acting on it.

1.2. Post – Earthquake Scenarios

Even after the guidelines provided by the different major countries of the world against the natural disasters for hospital structures, it had been seen that the when any natural hazard occurs, the component of the hospital buildings are affected, depending upon the intensity of that particular hazard. Most of the destruction has been observed in case of earthquakes. The seismic waves produced during that event, will affect the hospital structure, more or less depending upon the intensity and magnitude of the earthquake. In such cases, where the structure of the hospital is damaged, it is considered to be of utmost important and the repairing work of the same is done at very fast rate. With the advancement in the technology and science in the field of civil and structural engineering, one can easily detect the position of the failure of the structural component of the hospital building and then, it can be cured or repaired as per the damage observed after the earthquake. The technique called retrofitting is being implemented in such situations. Retrofitting may be defined as the technique in which the strength of the existing structure is increased by providing extra reinforcement to them. These reinforcements are provided on the outer periphery of the structure. The reinforcement may be provided in two different forms. In the first form, small bars are provided on the structural component and a rebaring liquid is inserted so that the rebar is fixed in its position. The primary objective of rebar in reinforced concrete structure is to carry the tensile loads and to avoid brittle concrete failure. Rebar is a reinforcement bar, generally formed from the carbon steel and is given ridges for better frictional adhesion to the concrete. The procedure includes: 1. Damage the portion (hacking of surface) where rebaring is to be done, 2. Drill holes of
appropriate diameter of the rebar, 3. After drilling holes, rebaring chemical is added into the holes with specialized

gun, 4. Immediately the rebars are inserted into the drilled holes (The setting time of chemical is 20 – 30 minutes.).

2. Literature Review

The study conducted by S. Khanmohammadi et. al.[4] was driven by the requirement to simulate and examine the

process of recovery of natural disasters, especially earthquake, affected hospital structures in direction to govern the

impact of plans of recovery accepted by the hospital administration. The seismic waves on the hospital structure easily

affects the basic five components of the hospital namely, 1. The hospital structure, 2. Staff, 3. Medical tools, 4.

Medicines and 5. Methodological systems, and thus totally disturb the services and the operations of a particular

affected hospital. Since the components of the hospitals are diverse, their process of recovery will be a complex
dynamic procedure. The model proposed in this study is dynamic in nature and is used to inspect the process of

recovery of any hospital from a universal point of consideration. The recovery procedure of the hospital includes the

quantification of the resilience of hospital building, implementing the same will give an idea how to use the available

resources after the occurrence of an earthquake. The research will allow to model the hospital building and then assess

its performance under the different load combinations. The whole presentation of the analysis of the hospital building

is not completely considered unless the individual performances of the different elements of the system aren’t taken

into consideration. The study also focuses upon to do a research which includes the affect produced by an earthquake

on the different components of the society including water supply systems, power supply systems, transportation

systems, etc. and how these affect the functionality of the hospitals post - earthquake. As a final point, a study is

needed to be conduct which contain a proposed model that can operated to determine the performance and recovery

of hospital structures under other natural hazards (Floods, Storms, etc.) and man-made disasters (Explosion, Fire, etc.).

The paper presented by [5] describes the modelling resolution effects on the performance of a steel hospital

building, which is located under Zone IV as per IS 1893:2016 [6]. The modelling includes 2 phases: 1. 2D Modelling

without Soil – structure interaction and 2. 3D Modelling with Soil – structure interaction. The analysis used in this

study were Pushover analysis and Dynamic analysis, the results of the two are obtained for both the different models

and are compared. The study showed that if the connections are designed properly, then their resistance increases and

the control over the floor drift and acceleration is improved. Also, the deformation modes of the foundation, which

includes: Sliding, Vertical and rocking, reduces the strength, stiffness and base shear, but an increment is observed in

the estimated displacements. The 3D analysis vary the sequence and the mechanism of the failure points of the hospital

building minutely as the desired stiffness of the structure changes, which in turn helps to shift the normal first system

yield point. The 2D analysis results in the reduction of the dynamic response of the building, which may lead the

analysis to be non – conservative.

R. Miniati et. al [7] methodology was based on integration of different approaches, the speedy vulnerable

assessment and a critical building modelling. The approaches used gives a vast analysis of all the structural and non –

structural components of the hospital building and their interaction with each other, which in turn make a hospital

building efficient in working during any time. The sheltering and the strategic function of the infrastructure was

considered with respect to Hospital Treatment Capacity (HTC) and Index Intrinsic Security (IIS). However, Hospital

Performance Index (HPI) conclude the response of a hospital building against the seismic waves by predicting the

expected damage to a hospital and its degradation. Fault Tree Analysis (FTA) approach is used, which gives more

perfect results than which were obtained from Loentief Model (used in L’Aquila Earthquake: April 06, 2009). At the

last, a Decision Support System (DSS) had been developed by prototyping process, which aiming to give th essential

and usable functional specification for a hospital risk management DSS. Correspondingly, an approach is to be adopted

by the decision makers of the civil department for planning a systematic risk management response, comprising the

responses of all local hospitals according to particular characteristic of individual health facility.

In the study conducted by A. Massi et al. [8], a technique was used to develop programs on populations of public

buildings concerning seismic risk reduction. It was primarily founded on the importance of a global risk index IR(t),

which is created by considering the ratio between seismic capacity and demand computed through detailed assessment.

Additionally, it focus on exposure of each structural component in a simplified style, which is through the assessment

of total floor area presumed as relational to the number of consumers and workers present in the structure. Another

vital point is the meaning of cost models: interactions between the anticipated strengthening costs and the present
capacity–demand proportion of a structure. The process had been applied to nearly 70 hospital structures, situated in Basilicata region of Italy, deprived of design of earthquake resistant. Capacity–demand proportions were presented from a wide seismic valuation program achieved by specialists, promoted by the Italian Department of Civil Protection and the Basilicata Region. Studies have been performed in view of four cost models which provide diverse connections between a known reduction of seismic risk on a structure and the capitals to be employed. The anticipated cost models (CM1–CM4) refer to four different mitigation approaches. Model CM1 objects at complete retrofit of all the structures aiming at a capacity–demand ratio = 1, as set by seismic codes for new structures. Model CM3 considers a risk marginally upper than model CM1 (i.e. αC¼0.8), while model CM2 is midway between CM1 and CM3 considering αC thresholds in view of the structure period. Lastly, model CM4 aims at a controlled progression without reaching the complete retrofit. Every model has the choice of thrashing and reconstruction of the structure. Some comments can be drawn concerning about the procedural application to different hospital building structures of Basilicata region. The comments comprised of the selection between the upgrading models and retrofitting strategies, which is somewhat complex in nature and wants a careful relative analysis amongst the remaining threat resulting from the application of the advance model and, on contrary, the extra time when some structures may be left without any earthquake provision while adopting different retrofitting techniques. The variations amongst the different strategies are depending upon the availability of the annual funds and the different levels of the risks are considered for a particular type of structure depending upon the levels of the availability of funds, which may lead to complete a program in a longer period of time, which increases the inflation rate, which can be easily understood by the models CM1–CM3 for a building which is set under observation.

C. Iasio [9] reveals that the one of the most important consideration at the time of the emergency response to seismic waves is the response coming from the local hospitals at a particular region. The methodology consists a structured analysis of all the elements of a hospital building. Also, to care the most affected people from an earthquake, an index of Intrinsic Security (IS) was considered, which assesses the planned as well as the shielding function of a hospital structure. The earthquake of magnitude 6 is considered in the Florence region of Italy. The results showed that the response from the local hospitals are quite good. The observations showed that with the effective planning, the people can be rescued and transfer to the hospital for their treatment. Thus, it means that if the structure of the hospital is able to withstand against the earthquake, it can be really helpful in treating the affected people afterwards. Thus, a systematic analysis has to be carried for the model of the hospital building in order to determine the strength of the hospital structure. And if any of the structure is not have the desired strength, then it should be retrofitted effectively. It also focuses on the development of the medical units near to the affected area so that the treatment capacity increase.

Yanuar Haryanto et. al. [10] did his study on The Oral and Dental Hospital at Jenderal University, Indonesia using Rapid Visual Screening method and evaluation by FEMA 310. The results are compared with a core of +2.0. The final score comes out to nearly 2.0, which means that the structure required a Tier 1 evaluation. This evaluation is done by using FEMA 310, which determines the possible deficient areas of the hospital structure. Thus, it means that the structure of the hospital will completely be collapsed if the lateral forces in the ground occurs, are equal or more than to the lateral forces occurred during a Maximum Considered Earthquake (MCE). The comments had been made regarding the structural and non–structural components of the hospital building and thus, it is highly advised that the structures should go through a detailed analysis and the necessary retrofitting work should be done as and where required.

The observation made by Nor Malyana Samsuddin et al. [11] has offered two results: 1. the significance of hospital preparedness characteristics and resilience tools, 2. the relationship of preparedness characteristics towards hospital’s resilience. The outcomes of the study conducted in Malaysia discovered that nearly 15 preparedness characteristics and 20 resilience tools are valued ‘very critical’ by the respondents. In disaster planning, human resources plays a vital role. They can be achieved by establishing Hospital Disaster Management Committee for every hospital in a particular area, which will be having the involvement of chief stakeholders. By working collectively, the resilience of the hospital against any hazard can be increased. In addition, various teachings regarding fire drills, earthquake drills must be given. The Hospital Emergency Incident Command System (HEICS) and different medical courses should be run which can in turn toughen the capabilities of the hospital administration to develop, implement and maintain healthcare functions during any disaster. Also, the structural components of the hospital building should be strong enough to withstand the effect of any hazard. If the structure of the hospital itself is not strong enough, then there will
be no use of any resilience tools at administrative level. Thus, the structure of the hospital should be modelled in such a way that it can be able to resist any hazard, and also provide shelters and treatment for the people who are injured during the disaster. Several techniques and methodology should be adopted by the hospital management to have a check on the structural as well as non-structural components of the hospital building. If any of the component gets failed, necessary action must be taken so as to make the hospital building “fit” for any condition.

K. Rattanakanlaya et. al. [12] revealed a great understanding of the understandings the disaster preparedness for floods in Thailand. Various strategies are adopted for the effective functioning of the hospital during floods. These strategies include designing and analysis of the hospital structure, making a pact with the other organizations in the particular area which provide resources at the time of the floods. His research presented treasured information in developing plans and execution of the policies for improving hospital disaster preparedness of flood in Thailand.

The study of V. Terzic, et. al. [13] discusses the suggestions of employing different analytical models conceptually for Reinforced Concrete structural walls; the models which takes coupled shear and flexural responses versus models in their consideration, where the responses are uncoupled. All these approaches are considered to have an estimation on seismic performance considering hospital buildings. The hospital building located in Los Angeles are analyzed with three levels of seismic hazard characterized with 2%, 10%, and 50% likelihoods of exceedance in coming next 50 years. Time Response Analyses are performed for each level of hazard, by taken into account a suite of twenty ground motions. The modeling method used to characterize shear behavior in nonlinear wall model are studied by comparing seismic repair losses, which are expressed in terms of the median and the 90th percentile estimates. The main concluded points of this study showed: 1) Coupled wall models generally foretell softer wall behavior within the plastic hinge region due to their ability to account for shear flexure interaction than uncoupled models. This leads to 70% to 130% of variation in median repair loss estimates obtained using uncoupled models when compared to coupled model, 2) The performance analysis tells that hospital structures considered with the improved designs relative to any other builds produce nearly 3 times larger total repair losses. The chief advantage of improved hospital building designs comparative to any other buildings reflects in meaningfully smaller remaining drifts that condense the chance of replacement due to the irreparable residual drifts. Though the RC structural walls system is a preferable system for hospital building because of their high value of strength and stiffness, they must be used with attention in the zones of high seismicity, and 3) Contributors to repair loss change with increasing hazard level as follows:

- For 50% in span of 50 years hazard level, acceleration complex components such as healthcare equipments and escalators, control building performance; where the structural behavior lies in the linear range.
- For 10% in span of 50 years hazard level, the connection between slab and column, and the provision of shear walls and glazed elevation, in addition with acceleration complex components including ceiling and HVAC units, primarily rule structures’ restoration cost.
- For 2% in span of 50 years hazard level, impact to structural loss is produced by harm to shear walls and slab-column connections. Other prominent providers are glazing, panels, healthcare equipments, lifts, ceiling, and HVAC units, but to a greater extent than for intermediate seismic quivering.

3. Methodology and Analysis

In this analysis, the software used is ETABS 2019. As per IS 1983: 2016, the Delhi / NCR comes under Category (ZONE IV), which means special attention must be given to the structure which are located in the same region. Also, while modelling the structure in ETABS, specific considerations must be given to the input data as per IS 1893: 2016. The analysis used in this study is Pushover Analysis. But, before running the pushover analysis, considerations are given to other static non-linear analysis also. The model is subjected to P – delta Effect and Gravity analysis, after which pushover analysis is performed. Also, for keeping the ductility effect into consideration as per IS 13920: 2016 [14], hinge formations in the beam and column sections are considered. The basic steps involved in the analysis done on ETABS are as follows: 1. Modelling, 2. Modification, 3. Loading conditions (Dead Load, Live Load, Super dead Load), 4. 1st Run Analysis, 5. Necessary Modifications (if required), 6. Advance Loading Conditions (Earthquake Load), 7. Advance analysis (a. P – Delta Analysis, b. Gravity Analysis and c. Pushover Analysis) and 8. Design. The modelling stage includes the modelling of the projected hospital. It includes the provision of the structural components of the hospital structure including beams, columns, slabs, shear walls. Firstly, the loads are defined: Dead Load, Live Load, Superdead Load, Earthquake Loads (in both lateral directions). After the analysis of 1st phase loading is done,
the time is to go for the second phase analysis, which includes non-linear static analysis, including P–Delta Effect, Gravity Analysis and Pushover Analysis. The results obtained from the pushover analysis are considered to be the final results and further modification/investigation of a particular hospital structure are based on the same results. The hospital building located in the southern region of Delhi – NCR: Faridabad, Haryana. The overall plan area of the hospital structure is 35770 mm X 15760 mm. The model is having two blocks, which are interconnected with each other only at one location. The “Type of Structure” is considered as a Multi – Story Rigid Jointed Frame. The hospital is a G+3 Storeyed building, with floor-to-floor height of 3.50 m, the thickness of external walls is 230 mm and that of internal walls is 115 mm. The grade of concrete used in this model is different as per the structural member. The grade of the concrete used for columns and beams is M 25. Whereas, the grade of the concrete used for slab is M 20. After assigning the basic structural components of any structure, i.e., Columns, Beam and Slabs, the next step is to assign the support conditions to the structure. Since the structure is located in Zone IV and is of important type, it is recommended to have a fixed support conditions. After determining the support conditions, the next step is to calculate the loads which is to be considered while analysing the structure.

| Structural Member | Dimensions                  |
|-------------------|-----------------------------|
| Overall Plan      | 35770 mm X 15760 mm         |
| Storey            | G+3 Storeyed Building       |
| Type of Structure | Multi – Story Rigid Jointed |
| Grade of Concrete | M 25 – Beams and Columns, M 20 – Slabs |
| Grade of Steel   | Fe 415                      |

Table 1. General Details of Hospital Building

Table 2. Dimensions of Structural Members of Hospital Building

| Structural Member | Dimensions                  |
|-------------------|-----------------------------|
| Slab              | 180 mm                      |
| Column            | 400 mm x 450 mm, 450 mm x 450 mm, 450 mm x 500 mm |
| External Beam     | 380 mm x 450 mm             |
| Internal Beam     | 380 mm x 450 mm             |

The loads are calculated by considering the densities of the different materials. The major types of the loads which is to be considered while analysing the structure are: 1. Dead Load, 2. Live Load, 3. Super – Dead Load and 4. Seismic Load. The Dead Load and Live Load are specified as per IS 875 Part I and Part II respectively. The Super – Dead
Load is assigned in ETABS as a special load. The Dead Load includes the loads of the external walls, internal walls and floor loads. The Live Load is considered as per the importance and type of the structure. The Super – Dead Load is assigned as a floor finish load. And the Seismic Load is assigned in accordance with IS 1893: 2016. The magnitude of superdead load is 33.096 kN/m², and that of live load is taken as 3.0 kN/m². The Superdead Load consists the load of the walls, load of plasters and load on slabs, with floor finish. The Seismic Loading is applied as per IS 1893: 2002/2016, by defining the following parameters as per the location of the building structure: 1. Zone Factor = 2.4 (Zone IV), 2. Type of Soil = I (Hard), 3. Importance Factor = 1.5 (Hospital Building) and 4. Reduction Factor = 5 (SMRF).

Fig. 2. Deformed shape of the building after Modal Analysis

After the loads is being applied, the nest step is to be assign the modal source. For assigning the modal source, we consider the worst possible case of the load combination as 1(DL + Super DL) + 0.25LL. The above-mentioned load conditions was considered to be worst after performing the analysis with different load conditions on Etabs. The main purpose of defining the modal source is to have the different modes in which a particular structure tends to fail. This is considered to be the first phase of the analysis, in which the loads and the mode source is defined and then, the analysis is run to find out any warning. One may also check the overlapping conditions of any property such as overlapping of the slabs while defining, providing two beams at one location mistakenly and so on. After the warning is positive and detect that there is no error, then we can easily see the deformed shape of the structure under the various load cases provided. After the modal analysis is done, we can see the different modes in which a structure can react before its complete failure. Also, we can easily see the modal frequency, circular frequency and the period of each respective mode. Now, the next step is to introduce the P – Delta effect. According to the P – Delta affect, it defines the relationship between the load applied on any structural member and the displacement caused by that particular load. The load may be considered as the axial force which can be defined as the load combination of dead load, live load and super – dead load. The deflection is the lateral displacement in either x or y or in both directions. These lateral displacement are generally considered by taking wind forces or seismic waves. The P – Delta analysis consists of 3 types of iteration: 1. No Iteration, 2. Mass Iteration and 3. Mass Iteration Factor. The first type doesn’t consider the effect of displacement in the analysis. Mass Iteration considered only one iteration. And the third type focuses on nth iteration. Since the analysis is considered on the different load conditions and combinations, the third type is used in the analysis. Also, the Mass Iteration Factor can be calculated by considering Newton Raphson Method. When the P – Delta analysis is performed, the scale factors have to be considered for maximum amount of dead load, live load and super – dead load. The values are taken as 1.5, 1.2 and 1.2 for dead load, live load and super – dead load respectively. These values are prescribed by ASCE journal on P – Delta analysis, which is considered worldwide. The next step is to do the Gravity Analysis. For which, we have to define the load type “Gravity Load” in the load cases. It is one of the non – linear analysis. While defining the gravity load, consider the results of p – delta analysis. Consider the mass source for getting different modes of the failure and apply the scale factors of 1 for both dead load and super – dead load and 0.5 for live load. Run the analysis for considering the most prominent displacement on the upper storey.
After the gravity analysis, one can easily determine the different modes and respective modal frequency, circular frequency and the period. Also, after performing the gravity analysis, one can easily see the data regarding the base shear and the displacement at which a particular storey moves under the action of the seismic waves. Now, the last step is to do the Pushover Analysis. The Pushover Analysis is considered to be one of the most efficient analysis on earthquake impact on the structure. It is to be keep in mind that while doing the pushover analysis on Etabs, one must do the P – Delta analysis and Gravity Analysis for getting the optimum results. For performing the pushover analysis, the first step which is to be considered is the formation of hinges on the structural components. The concept of the hinges are considered by keeping the importance of the ductility as per IS 456: 2000. In Etabs, the hinges are to be defined for both columns and beams. The hinges are provided to column and beams one after another. It is a free choice of selection of either beam or column first or later. But, the process of defining the hinges are different for beams and columns. For beams, while defining the hinges, the moment M3 is considered, i.e., the moment in the z – direction is considered, which is the prominent direction for the failure of beam. In case of columns, the load P, moment in the x- and y- directions are considered: M1 and M2, which is the worst load scenario for the earthquake analysis. The next step is to do the Pushover Analysis. For which, we have to define the load type “Push” in the load cases in different directions, i.e., the two lateral directions: x- and y- direction. It is one of the non – linear analysis. While defining the “push”, consider the results of p – delta analysis as well as gravity analysis. Consider the mass source for getting different modes of the failure and apply the scale factors of 1 for both dead load and super – dead load and 0.25 for live load. Run the analysis for considering the most prominent displacement on the upper storey. It is recommended to do the pushover analysis in the direction first which shows the maximum displacement after gravity analysis. After performing the pushover analysis in one direction, then the pushover analysis can be done in the other direction to get the best result for the case of deflection (lateral displacement) of the structure due to earthquake forces.
The green dots indicate that the structure started to be in a failure condition in Fig 4. As we follow the approach of strong column, weak beams; the beams will fail first and then, the column. The different colour represents the different failure environment, with least black and maximum for red. Since the hinges are provided for the pushover analysis, one can see how the structural component behaves in the earthquake incident. The ideal curve for the hinge analysis is a backbone curve. The variation in the idealised curve actually reflects the failure of that component. The variation is shown in terms of plastic rotations and moment. One can easily the curve and comment on the analysis. This hinge analysis is actually useful in the determination of the component which is failing up to which extent. And after getting the result, one can do the post-disaster structural techniques to regain the strength of the structure. Now, the next step is to strengthen the weak member, which is indicated by the “Red Dot”.

4. Seismic Strengthening

After performing the pushover analysis on the given hospital building (as per the Indian Codal Provisions of IS 1893: 2016), the maximum displacement of overall building is coming out to be 5.3 mm in x-direction and 0.5 mm in y-directions. The next step is to strengthen the existing building by determining the weakest structural members. In this particular hospital building, the weakest structural elements are found to be the columns: C 11, C 26 and beam B 4. Since, these three structural elements are forming a frame in the hospital building itself, the best possible retrofitting technique to make it strong against the seismic forces is bracing. Now, let us determine which type of section for the bearing will prove to be most effective in resisting the seismic forces. Bracings are made up of various steel sections such as Rod Sections, Channel Sections, Angle Sections, etc. In this study, following sections are used to strengthen the weakest frame in the building:

| Structural Member       | Dimensions         |
|-------------------------|--------------------|
| Circular Rod Section    | 10 mm dia          |
|                         | 12 mm dia          |
|                         | 15 mm dia          |
| ISA                     | 100 x 100 x 12 mm  |
|                         | 150 x 150 x 12 mm  |
|                         | 100 x 150 x 12 mm  |
|                         | 150 x 100 x 12 mm  |
|                         | 100 x 100 x 10 mm  |
|                         | 150 x 150 x 10 mm  |
After using the various sections mentioned above for the seismic strengthening of the hospital building, the following maximum displacement of the overall building is observed.

Table 4. Maximum Storey – Displacement (After Strengthening)

| Sections         | Maximum Displacement in x – direction (mm) | Maximum Displacement in y – direction (mm) |
|------------------|--------------------------------------------|--------------------------------------------|
| **Circular Rod Sections** |                                            |                                            |
| 10 mm dia        | 1.31                                       | 0.04                                       |
| 12 mm dia        | 1.35                                       | 0.05                                       |
| 15 mm dia        | 1.38                                       | 0.07                                       |
| **ISA**          |                                            |                                            |
| 100 x 100 x 12 mm| 1.83                                       | 0.06                                       |
| 150 x 150 x 12 mm| 1.325                                      | 0.05                                       |
| 100 x 150 x 12 mm| 1.74                                       | 0.05                                       |
| 150 x 100 x 12 mm| 1.35                                       | 0.04                                       |
| 100 x 100 x 10 mm| 1.84                                       | 0.06                                       |
| 150 x 150 x 10 mm| 1.30                                       | 0.05                                       |
| 100 x 150 x 10 mm| 1.70                                       | 0.04                                       |
| 150 x 100 x 10 mm| 1.29                                       | 0.03                                       |
| **ISMC**         |                                            |                                            |
| 150 mm           | 1.83                                       | 0.06                                       |
| 200 mm           | 1.84                                       | 0.05                                       |
| 250 mm           | 1.82                                       | 0.03                                       |
| 300 mm           | 1.85                                       | 0.04                                       |

5. Results and Discussions:
It had been found out that there is a notable decrease in the magnitude of the maximum displacement on the hospital building after providing the different bracing sections for the retrofitting purpose. In case of the circular rod sections, the maximum percent reduction is observed for 10 mm dia with an overall reduction in the maximum displacement of 75.28 percent in x – direction and 92 percent in the y – direction. When the angle sections of various dimensions are considered, it had been observed that not only the thickness of the angle section plays an important role, but also, the dimension of the outstanding legs of the angle sections is the decisive factor for determining the best possible section for the restoring the strength of the existing hospital building. Amongst the sections chosen for 12 mm thickness, the best section turns out to be 150 mm x 150 mm x 12 mm, showing the reduction in the maximum – storey displacement of about 76 percent in x – direction and 94 percent in y – direction. Amongst the sections chosen for 10 mm thickness, the best section turns out to be 150 mm x 100 mm x 12 mm, showing the reduction in the maximum – storey displacement of about 75 percent in x – direction and 90 percent in y – direction. When it comes to rolled – steel C – type sections, the results obtained were pretty competitive. The magnitude of maximum displacement, both in x – and y – direction, are quite close. Still, from the sections chosen, ISMC 250 shows the best result. The reduction in the x – direction and y – direction is found out to be 65.66 percent and 94 percent respectively.

![Comparison between the sections](image)

6. Conclusion:

Hospital structures are considered to be one of the most important structures in the society. Thus, they must be designed in such a way so that they can withstand all combinations of loads. Also, for the existing hospital buildings, proper method of retrofitting must be done so as to maintain its stiffness and strength to withstand the loads. In this study, an existing hospital building is considered and analyzed against the seismic forces. The weakest structural frame was determined. The bracing technique of retrofitting buildings is considered, with 3 different sections of varying dimensions. The three sections chosen were circular rod sections, angle sections and channel sections. From all the varying sections considered, circular rod sections of 10 mm dia shows the best result with an overall reduction in the maximum displacement of 75.28 percent in x – direction and 92 percent in the y – direction. ISA 150 x 100 x 10 mm shows the reduction in the maximum – storey displacement of about 75 percent in x – direction and 90 percent in y – direction. ISMC 250 gives the best result, with overall reduction of 65.66 percent and 94 percent in the x – direction and y – direction respectively. Also, it was found that if the same sections were considered, the best section which can be used for resisting the seismic forces is angle sections of varying dimensions of outstanding legs. In this study, ISA 150 x 100 x 10 mm shows the maximum reduction in the displacement – storey relationship.

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