BUILDING MATERIAL INFLUENCE ON RESPONSE REDUCTION FACTOR

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ABSTRACT

During strong earthquakes the nonlinear performance of building structures is determined by the response reduction factor (R) which is a seismic design parameter. Whereas, an extensive review of related literature indicates that the effect of viscous dampers on the response reduction factor is not considered. Therefore, this study proposed the response reduction factors for reinforced concrete structures equipped with viscous damper devices and investigated the effect of implementing such devices in reinforced concrete structures on the response reduction factor. Response reduction factor was formulated based on three aspects, namely, over strength, redundancy, and ductility factors. Fluid viscous damper is a device that enhances the performance of the building by adding damping. This study reviewed the recent developments in finding the influence of response reduction factor for RC framed buildings and their materials. Moreover, various approaches to pushover analysis and time history analysis have been mentioned in this review paper.

Keywords: Response Reduction Factor, Ductility factor, Viscous Damper, Soil-Structure Interaction, Pushover Analysis, Time History Analysis

I. INTRODUCTION

It is critical to understand the seismic behaviour of building materials with infill walls in both residential and commercial buildings since they are the most common structural system used in both types of structures. The basic purpose of conventional seismic structure design is to ensure the survival of human beings. Achieving this aim requires that the structure, no matter how badly damaged, does not collapse when subjected to a large amount of seismic energy. The structural ductility concept serves as the foundation for this strategy. It is taken into consideration while designing by employing response reduction factors to accommodate for this flexibility. The response reduction factor (R), which is a seismic design parameter, determines the nonlinear performance of construction materials during large earthquakes. It is probable that after a severe earthquake, it will be difficult to make any modifications to the building. The addition of damping (and, in certain cases, stiffness) to a structure enhances the performance of the building by allowing passive energy to be dissipated from the structure. The results of a previous examination into how a structure behaves when equipped with a viscous damper revealed that it was more capable of withstanding large lateral forces since the storey drift and forces in the members had been decreased. Building materials that are earthquake-resistant should be used in the construction of hospitals, police stations, fire department barracks, communication centres, airports, nuclear power plants, and other critical public safety infrastructure. These materials should be designed to withstand large earthquakes with minimal or no structural damage. Using fluid viscous damper devices, it is possible to customise the performance of various building materials to the exact specifications necessary. In order to make the construction more cost-effective, we may lower the size of the members and, as a result, reduce the mass of the structure, making it more earthquake-resistant.

II. RESPONSE REDUCTION FACTOR

When describing the extent of inelasticity that may be predicted in lateral structural systems during an earthquake, a response reduction factor is utilised. In order to achieve the design lateral force, it is necessary to lower the actual base shear force that would be created if the structure remained elastic during an earthquake (IS 1893). Seismic frame systems with finely defined geometries can withstand massive inelastic deformations without rupturing, which is how the R idea was conceived (Mondal et al, 2013).

The following equation, specified by IS 1893, can be used to determine design base shear:

$$V_d = \frac{Z \times I \times S_a}{2 \times R \times g}$$

Response reduction was first defined in the ATC 19 (1995) report, and the definition supplied in that report is expressed in the equation below:

$$R = R_\mu \times R_o \times R_r \times R_\xi$$

Response reduction, over strength, ductility, redundancy and damping are all included in R.

Seismic plan codes use force-based methods and damping decrease factors created from the impacts of thick damping on the removal reaction of flexible single-level of-opportunity (SDOF) frameworks to represent the damping given by beneficial damping. As per papers like ATC (1995), more hosing can diminish the structure's power reaction. Thus, coming up next is the reaction decrease condition normally utilized in research:

$$R = R_o \text{ X } R_\mu \times R_r$$

Overstrength Factor (R_o):

Code-required minimum seismic design strength divided by structure's surplus strength until substantial yield. Because of many contributing elements, such as partial load factors for gravity loads and safety factors for material strengths, the structure yields at a higher load than the design load. The confinement of concrete and ductile detailing prescribed in regulations contributes to the strength of concrete members that are bigger than those needed by serviceability and architectural considerations (Abdi et al, 2015).

$$R_o = \frac{V_y}{V_d}$$

If you want to know how a structure will behave in the event of an earthquake, you'll need to know what's known as the design base shear force (Vd) and what's known as the yield base shear force (Vy).

Ductility Factor (Rμ):

The hysteretic energy-induced nonlinear response of a structure is quantified using the ductility factor (). The idealised yield strength of the structure's idealised yield strength is achieved by lowering the elastic force demand. By taking use of the energy dissipation capability of well-designed and well-detailed structures, the ductility reduction factor () can reduce the structure's overall ductility requirement (). The maximum displacement for a structure's life safety performance is determined by dividing the maximum roof displacement () by the displacement at the yielding point () (Hakim et al, 2014).

The following is how Newmark and Hall (1982) devised the ductility factor:

$$R\mu = 1 \quad \text{for } T < 0.2 \text{ s}$$

$$R\mu = \sqrt{2\mu - 1} \text{ for } 0.2 \text{ s} < T < 0.5 \text{ s}$$

$$R\mu = \mu \quad \text{for } T > 0.5 \text{ s}$$

$$\mu = \frac{\Delta_{max}}{\Delta_y}$$

Redundancy Factor (Rr):

A sidelong load opposing framework's overt repetitiveness factor (Rr) measures the quantity of redundancies. In RC developments, second opposing casings, shear dividers, or their totals are the most ordinarily utilized sidelong load opposing arrangements. The redundancy in lateral load opposing frameworks relies upon the underlying framework picked since focal edges are made for gravity loads and edge outlines are built as sidelong load opposing frameworks. Because of the many lines of sidelong load opposing edge frameworks, the supported cement underlying framework with different lines of dormancy opposing outlining frameworks falls into the class of excess primary frameworks (Jalilkhani et al, 2020).

For excess outlining frameworks, the lateral load is produced by different casings in view of the overall solidness and strength properties of the different casings. For a design with a few lines of edges, the constancy of the outlining framework is more noteworthy when the opposition qualities are uncorrelated (i.e., autonomous). For frameworks with equal casings, ASCE 7 proposes an overt repetitiveness component of Rr = 1.0, which is utilized in this work on the grounds that the contextual analysis structures fall into this classification.Table-1 shows the ATC redundancy factor (Rr) (Luis et al, 2019).

Lines of vertical framing	Drift Redundancy factor
2	0.71
3	0.86
4	1.0

III. FLUID VISCOUS DAMPERS (FVD)

The expansion of damping (and, in specific cases, firmness) to a construction upgrades the exhibition of the structure by permitting uninvolved energy to be dispersed from the design. Energy dissemination gadgets are by and large used to diminish how much development that happens inside a design during a tremor. Assuming that the construction answers flexibly, these gadgets will likewise assist with diminishing how much power applied. Structures that answer in a manner that surpasses yield, then again, won't be relied upon to bring down force. For the incredible greater part of utilizations, energy dissemination is an attainable option in contrast to customary solidifying and reinforcing innovations, and it is relied upon to accomplish equivalent Performance Levels as a rule. Notwithstanding, while most of these gadgets would be fitting for projects with a Performance Level of Life Safety or Immediate Occupancy, their utilization in projects with a Performance Level of Collapse Prevention would be confined. Viscoelastic liquid dampers were initially utilized in the military and aviation areas, where they ended up being very powerful. Their use in primary designing was especially common in the last part of the 1980s and mid 1990s (Sajjan and Biradar, 2016). Generally, liquid thick dampers are developed of a cylinder head with holes that are loaded up with a gooey liquid, like silicone or a comparative oil. As a result of liquid orificing that happens when the cylinder head goes through the liquid, energy is disseminated by the damper and the cylinder can move further. Since the liquid in the chamber is practically incompressible, compacting the damper makes the liquid volume inside the chamber decline because of the cylinder bar region development. At the point when the volume is diminished, a reestablishing force is made. The employment of a run-through rod that enters the piston head, travels through the damper and then exits the other end of the damper is typical in order to avoid this undesired force from being applied to the piston. An accumulator can also be used to prevent the restoring force from being applied. Fluid is displaced by the piston rod, which is collected by the accumulator and stored in the makeup area once it has been displaced. When the rod retracts, a vacuum is created, which draws the fluid out of the system. In the example, an accumulator is connected to a damper by means of a cable (Dangol et al, 2019).

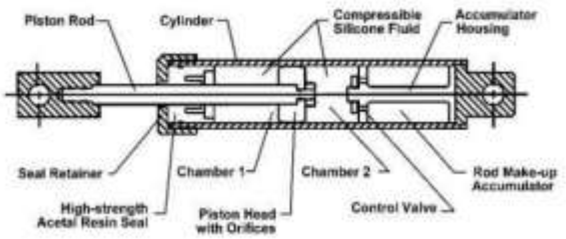

Figure 1: Damper with fluid viscous (FVD)

As the best damping force is speed subordinate, it is 90 degrees out of stage with the most extreme diversion of the construction to diminish both shear and twisting loads simultaneously. Besides, the power dislodging relationship is unaffected by the establishment of FVDs in a design (Zheng et al, 2019).

IV. EFFECT OF SOIL STRUCTURE INTERACTION IN FINDING R

When the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil, then this condition is called Soil-Structure Interaction (SSI). There can be different types of soil. For a hard type of soil, due to SSI, there will be little increase in time period 'T' of the building. But for soft and clayey type soil, base stiffness is decreased, and 'T' increment can be very large, which can create a negative impact on the overall structure. So, in order to design a building for such a large 'T,' it is very important to find out 'R' because for such building structures having high 'T,' we also consider the ductility of the members. There are mainly two kinds of SSI: Kinematic Interaction & Inertial Interaction. In Kinematic Interaction, due to EQ, there will be a free-field motion of the soil by which there will be Displacement of soil in a vertical and horizontal direction, but still, that free field motion of soil cannot displace the stiff foundation element. In Inertial Interaction, the weight of the superstructure transfers inertial force to the soil, causing deformation in soil. So, these effects have to be considered while finding out the value of the Response reduction factor (R) (Ubani et al, 2020).

Soil Structure Interaction:

In addition to the two components of SSI - kinematic and inertial - originally coined by Whitman, Roesset also discussed direct and substructure approaches to perform SSI analyses. In the direct approach of soil modeling, the entire soil, foundation & superstructure were modeled and analyzed in a single step. Mercado et al. (2019) evaluated SSI effects in tall buildings using direct approaches & described the importance of including SSI in numerical simulations as opposed to using conventional fixed-base building models. It was observed that SSI effects are properly analyzed by an indirect approach. Though it could give the most accurate result for soil parameters, it was very difficult to model soil with interaction with foundation & superstructure in a single step. The main difficulties lay in finding the stiffness of the soil. Later on, the Winkler model was developed in 1867 A.D for modeling of soil behavior. He gave the relation between bearing pressure of soil and deflection of soil with the help of stiffness of soil. Stiffness of soil was represented by springs and was called as modulus of subgrade reaction of springs (ks). Winkler's idealization represented soil medium as a system of identical but mutually independent, closely spaced, discrete, linearly elastic springs. After comparing the behavior of the theoretical model & actual foundation, it was seen that the Winkler model suffered from a complete lack of continuity in supporting medium soil. Later on, for Non-linear characteristics of soil deformation, different models were approached by different investigators like Filanenko Borodich Model, Hetenyi's model, Pasternak model & Kerr Model. Asrat Worku (2007) also derived spring formulas for short and long-term static soil deformation. There have been numerous parametric studies to date to establish the significance of considering SSI in structural design. Most of them suggest geometry of superstructure, foundation characteristics, soil modulus, and shear wave velocity profile in stratified deposits be the ones that affect their seismic response ((Ubani et al, 2020).

The behavior of soil is predicted based on the engineering properties of soil, vertical soil profile, and the alignment of the ground surface. The soil properties such as unit weight (γ), shear modulus (Es), Poisson's ratio (v), effective cohesion (c), friction angle (y) play a very important role in representing soil behavior. It was observed in certain studies that reduction in soil moisture content causes an increase in the lateral soil resistance. The empirical relations for γ, c & y are given by Bowels based on SPT penetration N values and type of soils. Also, from the theory of elasticity, we can get the other parameters of soil like Bulk modulus (k), shear modulus (G), and stiffness modulus (M).

V. PUSHOVER ANALYSIS (PA)

Starting from the seventies, pushover analysis has been performed by several methods. Standard guidelines were developed in America for pushover analysis ATC-40 in 1996 and FEMA-273 in 1997. The first known method was the Capacity Spectrum Method (CSM) started by Freeman and co-workers. Here, real structures were represented as an equivalent single degree of freedom (SDOF) model. Target displacement was found in CSM by intersecting the capacity curve with the demand curve. For the improvement of nonlinear static seismic analysis, FEMA 440 was developed in 2005. Later on, the Saudi Building Code (SBC 301) also satisfied acceptance criteria for the aforementioned methods by FEMA 273, ATC 40, and FEMA 440. However, no guidelines are available for pushover analysis by Indian Standard Codes till yet. By CSI back in 2014, Dr. Graham Powell mentioned that the CSM used by ATC 40, established in 1996, was found to be very inaccurate. Several Displacement coefficient methods were also developed, such as FEMA 356 displacement coefficient method and FEMA 440 displacement modification method, where target displacement or displacement demand was calculated by applying its formula (Erlicher et al, 2020). However, modified CSM was also developed, which could be comparable with the accuracy of DCM. All these methods used for PA used the equivalent SDOF model. However, there were some limitations of these all methods, like there were not the inclusion of higher modes in PA. Not only that but, also standard guidelines for the inclusion of building torsion were not available. This led to the development of Multimode PA. But, still, multimodal pushover analysis could not capture the entire seismic response because it was found that distortion of the capacity curve takes place by taking roof displacement as a reference point.

Soleimani et al. (2017) has mentioned that the authors Antonio & Pinho had concluded adaptive force-based PA has a relatively minor advantage over Modal Pushover Analysis (MPA), which is nonadaptive procedures. In order to address the distortion of the capacity curve, an Energy-based pushover analysis was developed. The Energy based pushover analysis (EMPA) is similar to MPA. In contrast to MPA, the work done by the lateral loads & torques through EMPA was considered as an index to compute the Displacement of corresponding equivalent single degree of freedom (EDOF) system. But, the application of EMPA was limited to 2D structures only. The development of multi-mode adaptive displacement-based pushover analysis using SQRSS or CQC combination rules depending upon the closeness of the modal responses also helped well to consider even small changes in the seismic load distribution along with the height of the structure at each step of PA. However, the drawback of adaptive pushover analysis is that the load pattern has to be updated in each step of analysis in accordance with the changes in characteristics of the structure due to nonlinearity (Bhandari et al, 2018). The latest method of 2020, known as E-DVA method, tried to include both the torsion effect and multi-mode effect by using alpha factors while doing a linear combination of modes. However, the implementation of this method has not yet been found in any commercial software.

VI. TIME HISTORY ANALYSIS

Ground motion parameters are the main things that are included in the Time History Analysis. Theory of Dynamics had already given the equilibrium equations of motion:

$$m \frac{\partial^2 u}{\partial t^2} + c \frac{\partial u}{\partial t} + k\,u + m\,\ddot{u}_g = 0$$

Figure 2: Equilibrium equation of ground motion

The above differential equations of ground motion needed to be solved. The solution of the above equation was obtained by standard procedures. Central Difference Method, Houbolt Integration Method (developed by Houboult in 1950), Wilson Ɵ method (developed by Wilson et al. in 1973), Newmark Method generally for linear time history analysis, and later on, the Direct Integration Method for non- linear time history analysis was developed. The direct Integration method was found to be the most effective method, among other methods. In the Direct Integration method, the equilibrium equations of motion are fully integrated as a structure is subjected to dynamic loading. Integration is performed at every time step of the input record regardless of the output increment. Recently, ATC 58 guidelines for non- linear dynamic analysis were developed in 2009 for seismic performance assessment of new and existing buildings, including fragility models (Reyes et al, 2017). Also, new guidelines ATC 72-1 and PEER 2010 was developed in 2010 for time history analysis for tall buildings. The important input ground motion records or parameters that are required to be found during THA are Amplitude components, Frequency components, and Duration components

The frequency components include Fourier Spectra & Power Spectra, which corresponds to the frequency content of GM itself, and Response Spectra corresponds to the influence of Ground Motion on structures with different first Eigen periods. Motion Duration represents the time required for release of accumulated strain energy along fault, thus increases with increase in magnitude of the earthquake. Relative Duration & Bracketed duration are the two types of motion duration.

These seismic input ground motion records is represented in terms of properly defined time series (example: Accelerograms) which needs to be consistent with seismic hazard at the site. In many building codes, this idea is associated with the concept of "Spectrum Compatibility". Seismic hazard at site is generally represented in probabilistic terms. Three types of accelerograms are developed till date. The first one is the natural set of records which are selected from the strong ground motion databases. Nowadays, real or natural earthquake databases can be found over the web, which allow to interactively search events and retrieve waveforms in digital forms with prescribed characteristics. The second type of accelerogram is Synthetic Accelerograms which are generated through complex mathematical models of the seismic source and wave propagation phenomena. Also, empirical ground motion prediction equations were developed by using regression analysis of databases of observed strong ground motion which accounts for possible nonlinear behavior of near surface soil. The third type of accelerogram is artificial accelerogram which are generally used to fulfill the gap of recorded accelerograms. For the generation of artificial accelerograms, target spectrum and envelope type were defined and calculation were based on algorithm but before target spectrum and envelope type, synthetic accelerogram which is simulated by the user was defined which was compatible with Target spectrum. Finally, after defining target spectrum and envelope type, Fourier transformation was applied to change from time domain to the frequency domain and correction to the accelerogram was carried out simultaneously. After the correction, again the accelerogram was returned to the time domain by applying inverse Fourier transformation & convergence were checked and decision was made whether further correction is required or not.

However, the main drawback of direct integration method is that it takes a lot of computational time. So, for practical purpose new method known as Fast Non Linear Analysis (FNA) Method was developed where implementation of Ritz vector instead of Eigen vector makes the less computational time by appropriately trimming beginning and end of acceleration record and down-sampling the remaining parameters while conserving significant frequency characteristics of the original record including its S-phase. The parameter to identify leading and trailing segments of the signal to be trimmed is the maximum roof displacement of an equivalent SDOF system. This parameter is selected over other parameter such as Areas Intensity because it represents the characteristics of both the ground motion and structural response. CSI commericial Software Company also recommends to do time history analysis by FNA method over direct integral method. Also, different speedup algorithm techniques have been developed recently to improve computational efficiency for time history analysis. Zheng et al. (2017) proposed the new speedup algorithm for super tall buildings in nonlinear time history analysis by utilizing optimizing and parallel computing techniques which depends on computer hardware condition by speeding Jacobian factorization with the help of INC, PSTP and PF algorithms (Reyes et al, 2017).

VI. CONCLUSION

It is observed that implementation of viscous dampers reduce the storey displacement, drift, acceleration occurred in RCC building and increases the base shear capacity. R factors are highly dependent on the height of building, viscous damper capacity and the input ground motion. Buildings with dampers can resist more lateral loads compared to building without damper at nearly same displacement. The advantage of viscous dampers is clearly demonstrated by increase in response reduction factor and improvement in performance of the building during an earthquake has been proven. Therefore, FVDs are effective for enhancement of RCC buildings performance when subjected to dynamic excitations.

Since, Non Linear Time History Analysis is time consuming and results of time history analysis are highly sensitive to methods of selecting and scaling ground motion records, Pushover analysis is widely being used for finding R with the help of plot of base shear vs roof displacement. Several approaches for Pushover analysis and their suitability were mentioned in this review paper. The Sequence of plastic hinge formation is the area which is less investigated till date. The time period of the building increases due to consideration of SSI.

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