UNIVERSITI PUTRA MALAYSIA

RESPONSE MODIFICATION FACTOR FOR STEEL AND REINFORCED CONCRETE STRUCTURES WITH VISCOUS DAMPERS

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By

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The response modification (R) factor serves a main function in the seismic design of building structures nowadays and is considered to be one of the seismic design parameters in the process of equivalent static analysis. In the last two decades, the application of damper systems as earthquake energy dissipation systems in structures has increased. However, an extensive review of the related literature indicates that the effect of the viscous damper on the response modification factor of steel and reinforced concrete structures has not been investigated. Framed by this context, the current study investigates the effect of implementing a viscous damper device in steel and reinforced concrete structures on the response modification factor.

In this research, steel and reinforced concrete structures with numerous stories were considered to evaluate the value of the response modification factor, which was formulated based on the following three aspects: strength, ductility, and redundancy factors. Structural frames were designed according to the UBC 1994 and IBC 2012 codes, and non-linear static analysis was conducted with the guidance of previous studies, such as the Applied Technology Council (ATC) 19 and ATC 40.

Nonlinear static analysis was performed using a finite element software, which considered structural models equipped with viscous damper devices in different arrangements. The bilinear approximation of the actual push-over curve was used to evaluate the required parameters, such as the base shear at yield point (V_y), roof displacement relationship at yield point (Δ_y), and maximum displacement (V_m).

Results showed that the response modification factor of steel and reinforced concrete structures equipped with viscous dampers is higher than that of structures without viscous dampers.

To verify the numerical analysis and formulation, experimental tests were conducted for the steel and reinforced concrete models, as well as the ARCS3D used for the reinforced concrete models. According to the experimental results and comparisons for the proposed response modification factor, using energy dissipation systems has an effective influence on the response modification factor and leads to a response modification factor with a higher value.

Based on the analytical results for all the different cases, the equations proposed for determining the response modification factor of the steel and reinforced concrete structures were furnished by viscous dampers according to the value of the damping coefficient and number of stories.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Master Sains

BALAS FACTOR PENGUBAHSUAJAN BAGI STEEL DAN STRUKTUR KONKRIT BERTETULANG DENGAN PEREDAM LIKAT

Oleh

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Response modification factor adalah ciri utama dalam rekabentuk seismic struktur bangunan masa kini dan ia adalah salah satu parameter bagi proses setara analisa static. Walaupun telah dua(2) dekad, sistem penebat diguna sebagai system pengagihan tenaga gempabumi dalam struktur banguhan, namun melalui semakan literature berkaitan nya , didapati kesan penebatan kepada rmf dalam struktur keluli dan konkrit bertetulang tidak diberi kajian sewajarnya.Oleh itu, disini, usaha dibuat untuk melihat kesan penebatan kepada response modification factor dalam struktur keluli dan konkrit bertetulang.

Dalam kajian ini, Struktur keluli, struktur konkrit bertetulang pelbagai aras di nilai untuk menentu angka response modification factor yang didasarkan kepada tiga aspek iaitu kekuatan, kemuluran , kelebihan. Rekabentuk struktur adalah menurut UBC 1994, UBC 2012 dan analisa statik tak linear dilaksana dengan panduan kajian terdahulu ATC 19 dan ATC 40.

Analisa statik tak-linear melalui pengisian unsure terhingga di gunakan menilai model struktur yang di pasang alat penebat. Beberapa susunan penebat pelbagai nilai di gunakan. Penghampiran bilinear lengkok daya dorong tarik digunakan semasa menilai parameter yang diperlukan saperti keterikan dasar pada titik alahan (Vy), sesaran atap berkait dengan titik alahan (Δy) dan anjakan maksima (Vm).

Keputusan kajian memdedahkan response modification factor bagi struktur keluli dan struktur konkrit bertetulang yang di pasang bersama system pengagihan tenaga adalah lebihtinggi di bandingkanresponse modification factor di struktur tanpa penebat viscous.

Bagi pengesahan formulasi persamaan dan keputusan analisa numerical, ujikaji dilaksanakan atas kerangka keluli dan kerangka konkrit bertetulang. Dari hasil ujian , response modification factor bagi system debgab agihantenaga adalah lebih tinggi dan response modification factor dipengaruhi oleh system agihan tenaga.

Berdasar keputusan analitika kes yang pelbagai, persamaan yang di cadang untuk menilai response modification factor bagi kerangka keluli dan kerangka viscous bergantung pada pengkali penebat dan bilangan aras.

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I certify that a Thesis Examination Committee has met on (date of viva voce) to conduct the final examination of (HESHMATOLLAH ABDI) on his (or her) thesis entitled(“Response modification factor for steel and reinforced concrete structures equipped with viscous damper”) in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the relevant degree.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

CHAPTER 1

INTRODUCTION

1.1 General

There are numerous natural hazards in the world but earthquake is a most destructive natural hazards that can result in severe social and economic impact. Earthquake engineering is a branch of engineering that is concerned with the estimation of earthquake impacts. It has become a group involving seismologists, structural engineer, architects, information technologists, geotechnical engineers, social scientists and urban planners. The earthquake engineering society has been reassessing their procedures since the past few years, in the wake of destructive earthquakes which caused wide-ranging damages such as loss of life and property. These procedures involve assessment of seismic force demands on the structure and then developing design procedures for the structure to withstand the applied actions.

Due to economic and architectural constraints, engineers are compelled to design structural systems which are cost effective and good-looking while adequately safe and strong to satisfy inhabitants who will live and work in there. Scarce resources of materials, man & machine power and time, especially in active seismicity areas; mandate the basic objective of structural design as to design buildings with capability to withstand due to strong ground shaking without collapse, but potentially with some significant structural damage. At the present time structural design philosophy residing in codes, emphasizes that complete safety and without damage, even in an earthquake with a reasonable possibility of occurrence, not possible to be achieved. However, letting some structural and non-structural damage, a high level of life safety can be economically achieve in structural design by applying inelastic energy dissipation system.

According to seismic codes, usually the design lateral strength is lower than the lateral strength that structures required to stay in the elastic range. Maintaining the structure inelastic range means that all structural and nonstructural members, subjected to lateral motion, are assured to return to the initial state with no permanent deformations and damages. In many cases preserving this state is far from being feasible and rational. On the other hand, going beyond the elastic frontier in an earthquake event may lead to yielding and cracking in members which can bring catastrophic results unless these inelastic actions are limited to a certain degree. At this point utilizing inelastic behavior definitely lowers the overall construction costs by reducing member sizes thus reducing material amounts and construction time also providing ease of operability and erection. Finding the balance in between is the major concern of a designer who is searching for the optimum design by means of seizing the members and making use of different structural systems.

To utilize inelastic behavior in design, first of all, effects of earthquake induced motion of the structure must be examined. Current engineering practice is capable of making close approximations of the structural properties and properly put them into operation of computer aided finite element analysis (formulation of the problem into a set of mathematical equations). Such as the mass, stiffness and damping properties moreover gravity loading conditions may be modelled. On the contrary the earthquake characteristics are unique. The ground motion is unpredictable and irregular in direction, magnitude and duration. Therefore past ground motion records serve as a starting point to form a basic understanding of the characteristics of the excitation such as the displacements, velocities, and accelerations. Structural engineering took advantage of these records by various schemes. Subjecting a model directly to a given motion record as known as Time History Analysis, may provide an insight to what will actually happen during an excitation. In the process of structural design an iterative progression takes place; this kind of simulation may be carried on for linear and non-linear models with different records but such an approach needs huge computational effort and time.

Consequently the Response Spectrum Method is preferred in routine application. The most simplified and striped method for seismic design is the Equivalent Lateral (Static) Load analysis which is easy to employ and the variables (relatively less in number) are defined in the codes.

Plastic design for steel and ultimate strength design for reinforced concrete members are based on inelastic performance of materials. For both design methodologies statistical studies played an important role in defining load factors since members shall not be designed for the working loads. However the overall inelastic behavior is another matter which is also studied by numerous researchers up to present date. Equivalent Lateral Load and Response Spectrum Analysis methods are the most used methods to evaluate earthquake resistance and design of structures since they are actually based on elastic static analysis. However, these are not universal analytical tools to allow for the perfect consideration of very complicated building behavior subjected to earthquake ground motions. A new procedure which called Performance Based Design is rising now, which implementing the inelastic static analysis (pushover) natively in design process, stepping ahead of above mentioned elastic procedures which are most of the time leading to poor approximations of overall behavior. The main approximation lies in the concept of Response Modification Factors. This value approach to assign discrete modification factors for structural systems may be very practical when it comes down to routine practice in engineering but simplicity brings higher uncertainty.

To judge the nonlinear performance of building structures when earthquake happen, Response modification factor will be used as seismic design parameters and since seismic design codes try to reduce loads. Damages due to earthquake are a worry to professionals, government officials, and the public. Nevertheless, we can neither predict the incidence of an earthquake nor accurately, estimate its amplitude, frequency contents, and duration. Also the structural capacity such as material strength always cannot be exactly determined. Brittleness data are necessary for seismic risk assessment studies to estimate earthquake-induced loss of life and property damage, also to estimate economic and to develop an emergency plan that can be helpful. On the other hand, to design the new building structures, nonlinear structural response should be obtained more or less by using Response Modification Factor (Seya et al. 1992).

The structures should be designed in a way that they have resistant enough against severe earthquakes. In other words, a structure not only should dissipate a behavior, but also it should be able to control the deformation and transfer the force to foundation through enough lateral stiffness in ground motions.

Earthquake loads that loaded to structural buildings are normally more than that they are designed for. This kind of reduction in design load by seismic codes is throughout the application of response modification factor (R-factor). During earthquakes, structural building typically behaves elastically and then inelastic analysis is essential for design. Inelastic dynamic analysis is slow and construal of its results need high level of experience. Recently Pushover analysis has being used to estimate inelastic response of structures.

Nowadays most of seismic design codes consist of the nonlinear response of a structure implicitly through a 'response reduction modification factor' (R). R factor helps designers to apply linear elastic force according to design while counting for nonlinear behavior and deformation limits.

The purpose of this research is to evaluate the Response Modification Factors of structures equipped with and without damper device and finalize the final formulation for evaluation of Response Modification Factor for structures equipped with viscous damper devices. In this study past observations and studies are reviewed. The response modification factor(R) simply represents the ratio of the maximum lateral force. Since, the response modification factor depends on overstrength, ductility and redundancy factor.

According to this research value of ductility, overstrength and finally response modification factor have been evaluated for steel structures and reinforced concrete structures. Results illustrate that the value of response modification factor for structures equipped with damper device is higher in compare when there is no damper device in structures. It establish that the factors such as number of damper (percentage of bay equipped with damper device), damping coefficient and even height of structure has effect on value of R factor and finally formulation finalized.

1.2 Background and Earlier work

To design earthquake loads resisting element, force reduction factor will be needed. Response Modification Factor proposed for the first time in ATC 3-06 (1978) that were selected according to observed performance of buildings during past earthquakes also on the estimation of overstrength and damping, etc. (ATC-19, 1995). Response Modification Factor consider as factors such as: overstrength, ductility and redundancy factor base on ATC-19 (1995) and ATC-34 (1995).

In the procedure to estimate the seismic force of structural building, R factor acts as an important part. As mentioned, Response Modification Factor consider base on ductility (μ), over-strength (Ω) and redundancy (ρ), since the dynamic response of structural activates these factors to reduce elastic force into inelastic loads beyond the elastic range.

To consider the overly behavior of any structural building when it is subjected to a particular one direction lateral loads, load Vs displacement curve will be used. When parameters such as ductility (μ), over-strength (Ω) and redundancy (ρ) evaluated during the loading procedures then the R factor can be developed and estimated. The response modification factor will be estimated as:

$$R = R_{\mu} \,.\, R_{\Omega} \,.\, R_{\rho} \quad (1.1)$$

The ductility factor (R_{μ}) can be intended from the evaluation of the translation ductility ratio. The relationship between the maximum elastic load (V_{ue}) and maximum inelastic load (V_u) can define the R_{μ} factor, in same structural building under inelastic behavior.

The essential studies about Response Modification Factor due to ductility have been done by Newmark and Hall (1982). Based on their study, ductility (R_{μ}) is sensitive to the natural period (T) of the structure and even there are five period of different range whichR_{μ} can be found according to different value. R_{μ}-μ-T for numerous ductility ratios and periods illustrates in Figure 1-1.

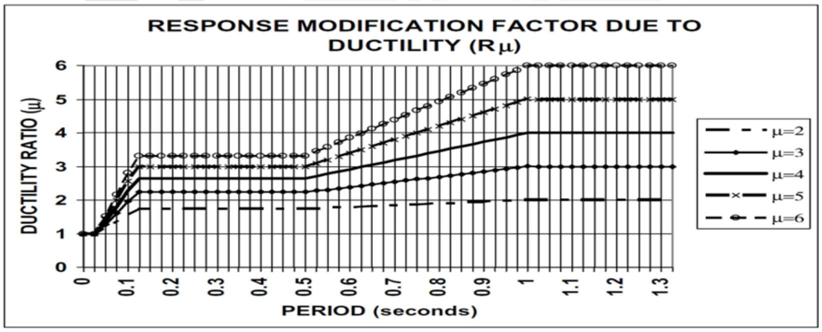

Figure 1-1. $R_{\mu} - T - \mu$ Curves (Newmark & Hall, 1982)

According to International Building Code (IBC, 2000), to evaluate the design seismic forces of structures which have been reduced, to evaluate the deflection amplification factor (C_d), to convert elastic lateral displacements to total lateral displacements, Response Modification Coefficient (R) will be applied even including effect of inelastic deformations. The values of R and C_d arranged in the IBC (IBC, 2000) are based on technical justification, observations of the performance of different structural systems in previous strong earthquakes and on tradition (NEHRP, 2000). The coefficient R is proposed to explanation for energy dissipation through the soil-foundation system, over-strength and ductility (NEHRP, 2000).

Numerous researches have been performed on the selection of Response Modification Factors (R) for the seismic design of structures. For example, Miranda presents a review of different investigations on the coefficient R, which is described as a strength reduction factor (R_μ). The study of Miranda suggests that the factor (R_μ) is mostly a function of the displacement ductility (μ), the natural period of the structure (T) and the soil conditions.

The structures should be designed in a way that they have resistant enough against server earthquakes and they should also provide comfort and peace of mind of residents who live there against weaker earthquakes. In other words, a structure not only should dissipate a considerable amount of imported energy by ductile behavior, also it should be able to control the deformations and transfer the force to foundation through enough lateral stiffness in ground motions. The final capacity of dissipated energy in every structure depends upon various factors such as: structures seismic parameters, characteristic of earthquake records, the environment condition of construction and place of structural building. Response modification factor is reflection of energy dissipation within the boundary of plastic with respect to the lake of overturning and big deformation in structure. Height of structure is a one of various parameters which is effective on the response modification factor (Abdollahzadeh et al, 2011).

Design a structural building to stay elastic is uneconomical and not easy to legitimatize for a rare earthquake type loading. Instead, it is an ordinary design principle to accept some seismic damage in a building which it does not guide to the fall down of the structure. The collapse will be avoided if the structural components are designed in a ductile manner which is expected to resist the excessive forces.

Damping in structural building is provided by inherent damping which is comes from structures and by supplementary damping that is by adding energy dissipation devices to structures. In building codes to consider for the effect of supplemental damping on the force and displacement response of buildings the damping reduction factor has been accepted. Researcher such as; Newmark and Hall (1982), Wu and Hanson (1989), Hanson et al. (1993) have done research on this effect.

1.3 Statement of the Problem

The equivalent lateral force method is a well-known approach in structural engineering because of the simplicity and reliability of calculating the lateral forces induced by an earthquake. In the mentioned scheme, the response modification factor (R) is one of the controversial issues to choose for a different structural system. Furthermore, the application of a supplementary energy dissipation system, such as the viscous damper, attracts much interest among engineers, experts, and researchers. A review of the literature indicates that the effect of the viscous damper on overstrength, ductility, and response modification factor is not available and that no information exists on the evaluation of the R factor of steel and reinforced concrete structure equipped with a viscous damper device. In addition, no report exists on the effect of the damping coefficient and height of the structure on the R factor when a structure is equipped with viscous dampers. Therefore, developing a new formula for evaluating the R factor is vital for structures equipped with a viscous damper device, given the effect of the number of dampers and damping coefficient in formulation.

1.4 Identified Gaps

i. No investigation exists on the procedure of performing the equivalent static analysis of steel and reinforced concrete structures equipped with a viscous damper device.
ii. No study exists on the evaluation of the R factor of steel and reinforced concrete structures equipped with a viscous damper device.
iii. No procedure exists for the evaluation of the R factor for structures equipped with a viscous damper device.
iv. No information exists on the effect of different parameters on the response modification factors of steel and RC structures equipped with a viscous damper device.
v. No investigation exists on the effect of the number of dampers, different damping coefficients, and height of structures on the R factor.

1.5 Objectives

The general objective of this study is to evaluate the R factor of steel and reinforced concrete structures equipped with viscous damper device.

Therefore specific objectives of this study are defined as:

i. To propose a computation algorithm for performing equivalent static analysis on steel and reinforced concrete structures equipped with a viscous damper device.
ii. To develop a new process of evaluating the ductility (μ), overstrength (Ω), and response modification factor of steel and reinforced concrete structures equipped with a damper device.

iii. To evaluate the effect of the number of dampers, damping coefficient, and height of structures of steel and reinforced concrete-framed buildings on the R factor.

1.6 Scope and Limitations of the Work

To achieve the said objectives, the following steps have been conducted in the present study:

The main aim of this study is to investigate the performance of steel structures and reinforced concrete structures designed according to the UBC 1994 and IBC 2012 codes, with non-linear static analysis conducted to evaluate their lateral load carrying capacity. Another aim is to assess the pertinent response modification factors based on the literal definition given by past studies and to finalize their formulation.

A 5-bay structural system is created in both directions for the 4-, 8-, 12-, 16-, and 20-story configurations of 5 different framing systems according to the number of the damper device in each floor and 3 different values of the damping coefficient (C). A total of 150 different structural models are analyzed to evaluate the R factors.

The resultant base shear is normalized by the equivalent lateral load proposed by the code. The design sections are chosen from a European section list and dampers from Taylor Devices are used in this research.

Pushover analysis is performed according to the Applied Technology Council (ATC) 19 (1995) prescriptions. Ultimate capacity pushover analysis is performed until the system becomes an unstable mechanism. Brief information and modeling property data are presented in every section to explain the benefits.

Some of the design conditions for the framing systems are predetermined, such as seismic zone, soil group, building importance, and gravity loading. These values are kept constant for all design cases.

The method of analysis for the response modification factor is implemented by considering the effect of a viscous damper on the R factor.

Equivalent static analysis is selected for steel and reinforced concrete frame buildings equipped with earthquake an energy dissipation system (viscous damper). Pushover analysis is conducted to determined the overstrength and ductility reduction factors.

The response modification factors are evaluated in accordance to the different damping coefficients, number of dampers, and height of structures.

To conduct this research, a new formulation for the response modification factors is proposed in the range of different damping coefficients.

1.7 Layout of the Thesis

The thesis has been divided into 7 chapters and the brief description about each chapter is described as below:

Chapter 1 highlighted the importance and the definition for the present investigation along with the objective and scope of the study.

The review of works related to response modification factor, application of R factor, nonlinear static analysis covered in Chapter 2.

Chapter 3 present the methodology of the thesis. The modelling of structural frames, different viscous dampers, pushover analysis and method of analysis for response modification factor illustrated.

The effect of viscous damper on response modification factor base on proposes value of R factor presented in Chapter 4 and 5. The final formulation for steel structures and reinforced concrete structures equipped with viscous damper illustrated in this chapter.

Chapter 6 present the verification of response modification factor for steel and reinforced concrete frames.

Major conclusion observed from the study carried out in this thesis presented in Chapter 7.

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