



UNIVERSITI PUTRA MALAYSIA

***RUBBER WALL DAMPER ELEMENT FOR REINFORCED CONCRETE
AND STEEL FRAME BUILDING STRUCTURES***

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AND STEEL FRAME BUILDING STRUCTURES**

By

MOHD AZMI BIN MOHD ZAIN

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
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DEDICATION

Every challenging work needs self efforts as well as guidance of those who are very close to our heart. My humble effort, I dedicate to my departed and lovely father and mother, who past affection, pray of day and night make me able to get such success and honour. Alongside me is my dearest wife, who leads me through the valley of darkness with light of hope and support to see the fruit of this labour. Thank you.



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RUBBER WALL DAMPER ELEMENT FOR REINFORCED CONCRETE AND STEEL FRAME BUILDING STRUCTURES

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The application of modern control techniques to diminish the effects of dynamic loads on building structures offers an appealing alternative to traditional design approaches. Rubber Wall damper (RWD) is one of the inventive passive energy dissipation device which enhance lateral resistance capacity and damping characteristic of the structures. RWD similar to fluid infill supplemental wall dampers yet is more suited for use in far field earthquake zone and is less expensive, maintenance free and economy. Here, a RWD is fabricated using Malaysian rubber, local steel and reinforced concrete structure, to reduce dynamic load effect and preclude vibration damage of buildings.

Critical review of literature indicates no analytical model available for numerical model of RWD in building structure. Furthermore, the building frames response analysis is realistic, only if nonlinearity due to material behavior is also taken into account. Thus, nonlinear dynamic analysis is a prelude to achieving both accuracy and economy in the structural design. The analytical and constitutive model for RWD are developed for purpose of numerical modeling and finite element simulation and evaluate effect of Damper in seismic response of structures. Various types of concrete framed buildings equipped by proposed device are analyzed and efficiencies of device was assessed. Additionally, through nonlinear dynamic analysis, the possibilities of arresting plastic hinge formations in structural components were investigated. The numerical analysis results showed the maximum horizontal displacement of frames with RWD diminished from 45% range up to 92%. Generally, the maximum story displacements dropped dramatically compared to similar response of the bare frame system.

In steel frame and Reinforced Concrete frames furnished by the RWD device, the maximum failure capacity improved approximately by 256% and 244% respectively. This proved the effectiveness of developed RWD device energy dissipation option in the buildings. Besides the numerical analysis, the prototype damper device has been fabricated and experimental test has been carried out to assess the functionality and performance of the developed adaptive systems with conventional systems. Experimental test results on prototypes steel and reinforced concrete frame subjected to cyclic displacement action, verified the efficiency of the RWD device, whenever implemented in to the bare frame. The ductility behaviour and failure mechanism are enhanced in both frame systems. The results proved performance of moment resistance frame furnished by above devices has been improved noticeable and the damper device is able to increase safety of building against severe earthquakes.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

UNSUR DINDING PEREDAM GETAH BAGI BANGUNAN STRUKTUR KERANGKA KONKRIT BERTETULANG DAN KERANGKA KELULI

Oleh

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Pengunaan teknik moden bagi kawalan mengurangkan kesan beban kenaan dinamik pada struktur bangunan adalah alternatif menarik berbanding kaedah kawalan secara konvensional. Peranti dinding peredam getah adalah peranti peredam tenaga pasif yang dengan penggunaannya dapat meningkatkan kadar peredam ufuk struktur dan tingkatkan keupayaan rintangan struktur mengufuk. Peranti ini menyerupai peranti dinding peredam bendalir, namun ia lebih murah, ekonomi, bebas senggaraan dan lebih sesuai digunakan di zon lapangan gempa jarak jauh. Peranti dinding ini direkabentuk menggunakan getah tempatan dan bagus guna dalam struktur keluli dan struktur konkrit bertetulang bagi rembatan kesan kenaan beban dinamik atas struktur itu dan seterusnya mengelakan kerosakan bangunan dari kesan gegaran.

Semakan kritikal menunjukkan ketiadaan model analitikal redaman tersedia untuk sistem paduan dinding peredam getah dalam struktur bangunan. Selain itu, tindak balas anjakan struktur berangka lebih realistik, jika ciri tak lurus bahan melewati ciri sifat anjakan juga diambil kira. Oleh itu, analisis dinamik tak lurus adalah metod ujian awalan untuk mencapai ketepatan dan ekonomi dalam rekabentuk struktur. Model konstitutif dinding peredam getah telah dibangunkan untuk tujuan permodelan berangka dan mensimulasi unsur terhingga dan menilai kesan penampakan sebagai tindak balas seismik struktur. Pelbagai jenis struktur konkrit bertetulang yang dilengkapi oleh peranti yang dicadangkan telah dianalisis dan kecekapan peranti telah dinilai. Di samping itu, melalui analisis dinamik tak lurus, kemungkinan memangkas pembentukan ensel plastik dalam komponen struktur telah disiasat. Angka analisis keputusan menunjukkan anjakan mendarat kerangka dengan dinding peredam getah berkurangan daripada 45% sehingga 92%. Secara umumnya, terdapat penurunan mendadak ensel berbanding kerangka tidak dipasang Peranti dinding peredam getah.

Bagi bangunan kerangka keluli dan konkrit bertetulang yang dibekalkan oleh peranti dinding peredam getah, kapasiti kegagalan telah meningkat kira-kira sebanyak 256% dan 244%. Ini membuktikan keberkesanan peranti dinding peredam getah bagi dissipasi tenaga dalam bangunan. Selain analisis berangka, prototaip dinding peredam getah telah direka dan ujian eksperimen telah dijalankan untuk menilai fungsi dan prestasi sistem peredam getah berbanding sistem konvensional. Keputusan eksperimen ujian pada prototaip rangka keluli dan konkrit bertetulang tertakluk kepada anjakan kitaran, mengesahkan kecekapan peranti dinding peredam getah, apabila dilaksanakan pada kerangka bangunan. Sifat kemuluran dan mekanisme kegagalan di sistem rangka bangunan dipertingkatkan. Keputusan membuktikan prestasi bangunan kerangka yang dibekalkan peranti telah bertambah dengan ketara dan peranti Peranti dinding peredam getah mampu meningkatkan keselamatan bangunan terhadap gempa bumi yang kuat.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
1S1B	A two dimensional, portal RC frame
3SSB.	A two dimensional, single bay, three story RC frame
5SSB.	A two dimensional, single bay , five storey RC frame
3SSB_8SSB	A coupled two dimensional RC frame consist of two(2) unsymmetrical , two bay, three storey RC frames and a single bay, 8 storey RC frame
Twin_10SSB	A two dimensional, twin single bay, 10 storey RC
3D5SSB	A three dimensional, one by one bay, five story RC frame
3D8S2X2B	A three dimensional, two by two bays, 8 storey RC frame
3D3S2X3B.	A three dimensional, three by two bay, three storey, RC frame
ADF	Anelastic Displacement Field
ARCS3D	Nonlinear Analysis of Reinforced Concrete Structures Equipped with Earthquake Energy Dissipation Subjected to Dynamic Excitation
ATC	The Applied Technology Council (ATC) protocol for cyclic seismic testing of components of steel structures
DOF	Degree of freedom
ETP	The Energy Technology Partnership
FEMA	The Federal Emergency Management Agency
GHM	Golla-Hughes-McTavish
GMM	Generalized Maxwell Model
HDPR	High Damping Performance Rubber
IDARC	Inelastic Damage Analysis of Reinforced Concrete frame shear-wall structures

LVDT	Linear Voltages Displacement Transducers
MRF	Moment Resisting Frame
MPD	Mass Proportional Damping
NCEER	the National Center for Earthquake Engineering Research
NEHRP	National Earthquake Hazards Reduction Program
PH	Plastic Hinge
RC	Reinforced Concrete
RWD	Rubber Wall Damper
SAP2000	Structural Analysis Programs series 2000.
USA	United State of America
VE	Viscoelastic

CHAPTER 1

INTRODUCTION

1.1 General

One of the most feared natural disasters that happen in almost all continents is earthquake. An earthquake is caused by a sudden slip on a fault. The tectonic plates are always slowly moving, but they get stuck at their edges due to friction. When the stress on the edge overcomes the friction, there is an earthquake and that releases energy in waves that travel through the earth's crust and creates seismic waves that we feel. There are a wide variety of earthquake effects - these might include a chasm opening up or a land drop of many meters across a fault line. Therefore, to design an earthquake proof building which is guaranteed to resist all possible earthquakes poses a huge challenge to building engineers. Notwithstanding, it is possible during the design and the construction process to build in, a number of earthquake resistant devices, and along with applying advance earthquake engineering analysis techniques, an engineer could provide safe building and would increase enormously the chances of survival of both buildings and their occupants. The application of earthquake resistant devices as the modern control techniques to diminish the effects of earthquake excitation (dynamic loads) and tsunami wave on building structures offers an appealing alternative to traditional design approaches.

There are many techniques introduced to enhance lateral resistance of structures and energy dissipation capabilities such as Active mass driver damper, Active tendon damper, Controllable fluid damper, Variable friction damper, Oil damper, Hysteretic damper, Visco-elastic damper, Viscous damper, shear wall and Base isolation systems. Collectively these control involved the adding of anti-seismic devices into the building structure to mitigate vibration in building or dissipate vibration energy off the system. The base isolation, for instance, the functions of a base isolation/dissipation system are generally one or a combination of the following: supporting gravity loads and providing for lateral flexibility (period shift), restoring force and energy dissipation (either of hysteretic, in the case of displacement activated dampers, or viscous nature, in the case of velocity activated dampers)(D J Wagg, S A Neild, (2010)). Despite the role performed by the base isolation, some filtered energy do get to the structure and here, supplementary energy dissipation devices are used to mitigate the effect of this energy to the building.

According to their performance, the anti-seismic devices can be grouped as :- rigid connection devices (e.g. lock-up devices), linear devices, non linear devices, viscous dampers devices, isolators devices (e.g, rubber bearings). Common types of anti-seismic devices are: Elastomeric bearings: Natural Laminated, Lead and High Damping Performance Rubber (HDPR) Bearings; Sliding devices; Friction Dampers; Metallic Dampers, Yielding steel systems, lead extrusion devices; Viscous and Viscous-elastic Damper; Self-centring Dampers: Shape Memory Alloys.

Researchers are now looking at the effectiveness of using rubber dampers within the building frame, to enhance the structural performances against lateral forces. HDPR as the damping medium in a passive damper is providing much interest among researcher. HDPR material is a damping medium in the solid visco-elastic wall damper devices. These dampers generally consist of solid elastomeric plates bonded to steel plates. The elastomeric plates exhibit both viscosity and elasticity and their mechanical properties depend on loading frequency, deformation amplitude and temperature.

The use of HDPR in energy dissipating devices in structural systems is a very promising idea in term of controlling the response under dynamic actions like wind or earthquake. The use of HDPR does, however, entail some problems because its dynamic behaviour is not completely understood and the few HDPR models that exist are not completely satisfactory for seismic analysis of structures equipped with HDPR based dissipation devices. More experimental tests need to be performed to obtain more accurate information about the behaviour of the material under cyclic shear paths with different strain rate and strain amplitude.

The issue is ; previous studies about seismic response of building with supplemental wall dampers equipped in the building; consider only the performance in one element with single degree of freedom and with much limitation. So, there is lacking of knowledge on behaviour of structure in 3D (3D) formed and is equipped with Rubber Wall Damper (RWD) . Furthermore via literature review, no information is available on 3D nonlinear, formulations of framed structures, equipped with nonlinear RWD element. Adding that, proper physical and material modelling of RC frame building equipped with RWD is not seen. There is no report on nonlinear RWD element compatible with frame structures, hence the interest for this study. The aim of this study is to explore capability of RWD in diminish response and damage of structures under dynamic excitation and vibration. For this purpose, the formulation and constitutive model of RWD will be investigate and proper numerical and finite element model for framed structures with supplemental RWD will be establish. So, nonlinear time history dynamic analysis of structure under dynamic load excitation will be performed and effect of RWD in reduction of structural response in terms of structural movement and occurring plastic hinges in structural members will be evaluated. Result of numerical analysis will be verified through experimental test which will carry out for frame structure with supplemental RWD under cyclic loads. Eventually through numerical and experimental result, potential of RWD for implementation in design of structures under dynamic loads and retrofitting and rehabilitation of existing buildings will assess with consider of costing. RWD designs comes with approaches of analysis and design, will be the physical industrial product realized from this study which will be widened the list of improved rubber product in Malaysia.

1.2 Research hypothesis

Energy dissipation cover any component used to reduced the movement of structure under dynamic excitation (by wind, earthquake alike). Passive energy dissipation method attempts to reduce the demand on the structure rather than the usual approach of adding capacity, hence the aim is provides Capacity greater than Demand. Within the passive anti seismic devices, four main categories of devices used are: 1. the yielding metal devices energy dissipated through hysteresis yielding, 2. the friction devices energy dissipated through frictional hysteresis, 3. viscous dampers energy dissipated through fluid viscosity and 4. Visco-elastic damper-energy dissipated through material viscosity. This study focus on the last category of the damper type .From the literature review it is further observe that little or no information is available on 3D and nonlinear formulations of framed structures, equipped with nonlinear RWD element. Furthermore, proper physical and material modelling of RC frame building equipped with RWD is not seen. Additionally there is no report on nonlinear, 3D RWD element compatible with frame structures and the literature indicated lack of investigation on damage detection of RWD device during earthquake which play important role in structure safety. Notwithstanding It is noted that there are some study about seismic response of building with supplemental wall dampers but the study do mostly consider the performance of one element in single degree of freedom with many limitation. So, there is lacking of knowledge on behaviour of structure equipped with passive , non linear, 3D RWD compatible with frame structure. The aim of this study is to explore the capability of RWD in diminish response and damage of structures under dynamic excitation and vibration. For this purpose, the constitutive model of rubber will be investigated and proper numerical and finite element model for framed structures with supplemental RWD will be establish. The study hypothesis is the supplementary RWD fitted in the moment resisting frame structure will dissipated dynamic excitation energy through damping action of rubber within structural frame system. The developed mathematical models of RWD are presented in this study. The assessment procedure of frames' response equipped by RWD subjected to dynamic load, are divided in two general phases include experimental test and numerical analyses. So, nonlinear time history dynamic analysis of structure under dynamic load excitation will be performed and effect of RWD in reduction of structural response in terms of structural movement and occurring plastic hinges in structural members will be evaluated. To begin, a structural control device, the RWD is developed. The device is a non gravity load carrier, fixed to the main structural frame and it provides supplemental damping to the structural frame. The following shall be elaborated later in the chapter. In RWD device, rubber sheets sandwiched between steel plates play crucial roles in system dampers, so, the damper formulation has been developed with reference on the steel plate rubber sandwiches layer concept. The industrial design and fabrication of RWD devices based on reasonable specifications have been proposed. The mathematical models of RWD devices with considering the attached connection is formulated and is implemented into specific finite element program developed by prior studies by Thanoon (1993) and Hejazi et al. (2013). Parametric study has been conducted on RWD's geometry specification and materials by aid of 3D nonlinear time history dynamic analyses for dissimilar models. In addition to that, experimental section consists of cyclic test. Cyclic test conducted is based on displacement control approach in steel and RC frames. Three steel and two RC frame specimens subjected

to cyclic displacement history on their top nodes. These models included of frames with and without attached RWD devices and conventional Cross braced steel frames. The impacts of RWD applications in steel frames are compared with bare and brace frames in terms of ductility characteristics, maximum capacity and the same impact in RC frame is compared with bare RC frame. Finally, the results from experimental and numerical test has been compared and verified.

In the proposed model, a frame building with earthquake energy dissipation system is idealized as an assemblage of columns, beams, damper devices appropriately connected. The use of this model facilitates the establishment of a global structural behaviour especially in two dimensional (2D) and 3D non linear static and seismic/dynamic analysis. Then a special finite element program code is developed for analysis of RC building furnished by viscous damper under dynamic load excitations. A mathematical model for RC frame members with supplemental viscous damper element is presented here. To get the true behaviour of a building under different types of loading and earthquake energy dissipation system, all types of the elements in a building are to be carefully model. The ideal starting point in establishing an analytical model for nonlinear analysis of a building would be to take the individual members and assign material behaviour characteristics in the form of stress-strain laws. The stress-strain relationship would then be used in conjunction with the basic member geometry and basic assumptions of the nature of the deformations, to establish the structural behaviour.

1.3 Brief description of present work

In the present work, the new effective RWD have been designed and developed with the use of local materials -Malaysian rubber , steel, bolts and nuts along with advance technology and techniques available “analysis of RC structure in 3D (ARCS3D)”, to analyze dynamic load effect and preclude vibration damage of buildings. These developed dampers is composed of two layers of HDPR sandwiched between steel plates. The supplemental HDPR wall device installed in the buildings structural system is expected to absorb energy to effectively reduce vibrations caused by earthquakes and wind. Based on literature, there is lacking of knowledge on behaviour of structure equipped with RWD especially for RC structures which are the common type of structures in Malaysia. The RWD component can be implemented to any structure which is subjected to vibration and it can be assumed to assure the serviceability and safety design criteria. Mathematical model of RWD are developed for numerical modeling and finite element method simulation. The study of building frames response, would be more realistic, only if nonlinearity due to material behavior is also taken into account. Thus, nonlinear dynamic analysis is a prelude to achieving both accuracy and economy in the structural design. The performance of RWD is evaluated by aid of dynamic analysis with considering the effect of RWD element. The results reveal the efficiency of wall damper system to diminish and dissipate the energy compared with conventional system. On the other hand the replacement of rubber as damping material in wall dampers compared with viscous substance, in terms of fabrication cost and maintenance fee is more desirable and cost effective. An analytical model of wall damper will be formulated based on Rubber constitutive law

and a finite element algorithm for the analysis of RC framed structures with supplemental RWD will be developed. A nonlinear time history dynamic analysis of structure under dynamic load excitation will be performed and the effect of RWD in reducing the structural response in terms of structural movement and occurring plastic hinges in structural members will be evaluated. Then based on numerical model, prototype of RWD will be fabricated and result of numerical analysis will be verified through experimental test which will be carried out for frame structure with supplemental RWD under cyclic loads. Eventually through numerical and experimental result, potential of RWD for implementation in design of structures under dynamic loads and retrofitting and rehabilitation of existing buildings will be assessed with consider of costing. RWD comes with approaches of analysis and design, will be the physical industrial product realized from this study

1.4 Motivation for the current study

Malaysia has enjoyed a relatively free event from earthquake but during the past two decades, Malaysia's fate has changed. In the west coast of peninsula Malaysia, report of tremor in major towns – Kuala Lumpur, Butterworth, Johor Baru have always being aired in the local news and media. Janda Baik in Pahang had experience of intermittent shake (rithcher-3.6) and at Tawau in Sabah, similar shake had also been reported. In 2015, the first casualty from earthquake occurred on the Mount Kinabalu. Many houses were also damaged in the aftermath of the Sabah earthquake (rithcher-6.0). Shake was also reported happened in the vicinity of Kuala Berang, besides the Kenyir Dam in Terengganu – West coast of the peninsula Malaysia. The events above showed Malaysia now, share effect of the wave from earthquake and Malaysians must live the experience of shake from earthquake originated from Indonesia or at Sabah and at Janda Baik. This poses new threat to existing old house, institutional building and infrastructure. Most existing buildings were of RC frame structure and during those years, buildings were constructed to detail using CP110/BS8110-part 1. The detailing then falls short of meeting prescriptive seismic detailing requirement observed in codes and standards for new buildings in seismic active zone. Further, local engineers are now facing a challenge for evaluation and retrofit using code based elastic analysis methods. Elastic analysis approach is now, no longer feasible.

At present, seismic rehabilitation of existing buildings uses the notion of performance-based limit states and FEMA, 2005 and ASCE/SEI 41-06 provided the first comprehensive guidance on the use of nonlinear analysis in design. As a result, seismic evaluation and retrofit of existing buildings has been one of the primary drivers for the use of energy dissipation devices and the seismic-rehabilitation required nonlinear analysis in engineering practice. Linear analyses are no longer sufficient to provide detailing needs for building to be constructed. Non linear analysis took its place, which indicates that structural behaviour under dynamic load are analyzed with respect to three dimension displacement, rotation and plastic hinge formations in the building. To extend the service life of the presence building, retrofitting is seen as a reasonable solution. For this purposes, passive devices are more appropriate for field applications since they are a cheaper option yet effective

to check the seismic performance of the structure under various earthquake scenarios(Chen et al. (2010)). Building structure do need approximately 15–25% of additional damping as a desirable range in the damper designed buildings(Lee and Taylor (2001)). Viscous damper devices is a favorite choice in upgrading the building damper. Uetani et al. (2003) proposed a practical method for optimum structural design of building frames with viscous dampers. The method firstly addresses issue on the stiffness design of a reduced shear-building model equipped with viscous dampers. Then an optimum design for building frames was performed under static design loads. A drawback in this method is that the viscous fluid is expansive and the devices used are therefore expensive. Hence a cheaper material option is therefore sought after. Another drawback is viscous damper is still a relatively new building technology yet to be further developed and studied (Ying Zhou et al (2012)). Ibrahim et al. (2007) proposed a new elasto-plastic device that consists of a block of a HDPR sandwiched between steel plates which are allowed to yield to provide additional energy dissipation. Karavasilis et al.(2011) experimentally evaluated the hysteretic behaviour of a new innovative compressed elastomer damper developed by Sweeney and Michael and used the design procedure of Lee et al. to design steel moment resisting frame (MRF) with compressed elastomer dampers. A sequential asymptote formulation to model the cyclic behaviour of ultra HDPR dampers was developed by Sause et al. (2011). Many researchers have performed individual visco-elastic damper tests and developed models to predict damper behaviour under earthquake loading. Tsai and Lee (2001) and Kasai et al.(1998) studied the effect of loading rate and temperature on visco-elastic materials and proposed fractional derivative models to predict damper behaviour. Lee (2001) studied the behavior of elastomeric dampers made of ultra HDPR and found from characterization tests the behavior of these dampers to be less sensitive to frequency and ambient temperature compared to conventional viscoelastic dampers. Fu and Kasai (1998) presented a simplified theory to design viscoelastic dampers for a given Moment Resisting Frame. Lee et al. (2001) presented a simplified design procedure for buildings with viscoelastic or high-damping elastomeric dampers. The design procedure has been used recently to study the effect of the variation in steel MRF properties and damper design criteria on the design of steel MRF with elastomeric dampers .

The use of HDPR provides cheaper alternative to viscous fluid and those researcher above had conducted study on the material, yet those studies centres on seeking the characteristic behaviour of rubber as a damping medium. The piece of rubber that was tested was basically a small sheet size. Notwithstanding, the result from the test have shown that rubber do posses the elastic properties and able to provide supplementary damping on a moment resisting frame structure. As Malaysia is a rubber producing state, this option to study RWD is feasible and if positive result is obtained, the product could be implemented on existing building in this country as a retrofit damper device and to mitigate the damaged of the house from the oncoming shake of the ground in the event of new earthquake. A 3D , non linear analysis is necessary to provide the manner of fitting the rubber wall devices to the moment resisting frame. Hence a non-linear analysis method is also seek to aid fitment of the damper device into the building frame.

Furthermore, Sadeck et al. (2006) identified some limitations in the FEMA 273 [17] procedures for the design of structures with velocity-dependent passive energy dissipation devices based on the analysis of single-degree-of-freedom structures. One of the major limitations includes a non-conservative estimation of peak response and base shear when using a constant reduction factor to obtain displacement response of short-period structures and assuming a harmonic response to compute the peak velocity, story and base shear.

Thus, this study observed, there is no report on nonlinear 3D RWD element compatible with frame structures. There are no commercially available finite element code which utilize column, beam and nonlinear RWD element for dynamic inelastic analyses of frame and be capable to optimize the structural control system based on non linear response of framed building. The assessment, retrofitting and rehabilitation techniques of frame buildings with passive control device such as RWD are not addressed and need further studies.

1.5 Statement of problem

From the brief review of literature of earlier works it is observed that:

Most buildings previously constructed from year 1970 till 2010 in Malaysia are of RC and are still serving the public, yet, are prone to the dynamic action accrued from earthquake, tsunami and traffic movement via underground passage. It has been observed these buildings were analyzed by static action to ultimate limit state and designed likewise, but, checks on service limit state, yet in her life span, the material deteriorates, drop in modulus of elasticity. For retrofitting, static analysis no longer work, the servicing action is dynamic in nature and has two additional generated action –inertia and inherent damping action which changes the former static equilibrium into a dynamic equilibrium. Hence 3D nonlinear, formulations of framed structures is needed to handle the present analysis needs. Yet again computational complexities and long time analysis process burdens the engineers and accordingly simplification, alternative calculation is sought, only to realise that building still crumbles down during earthquake. This is a tell-tale, showing the previous analysis has its shortfall and not pin pointing at the source of the problem which is matching the dynamic action against material response and subsequent responding in mode variance resisting against the action that is in the way of cyclical transformation between strain stiffness energy, inertia (mass) energy, damping energy and beyond the yield limit of the material.

Based on the extensive review of literature it was found that: Supplementary damper devices (passive, active) placed important function to provide effective damping in a structural frame system as the structure inherent damping has time and again been observed not suffice to release unwanted energy and this caused the reinforced frame section to rupture. The event of collapse buildings near column head and foot testify this event. The element of cost to retrofitting old frame RC building is a mind boggling issue too. Cheap option is greatly appreciated, yet, the prevailing method

and material use is rather expansive. Even for new RC frame structure, adding supplementary damper should not increase in the present construction cost and should be provided at the same cost if not lower.

This call for the need of performing on 3D nonlinear numerical time history analysis on structure and cheap option of supplementary damper for the safety of the common public building dweller or consumer. So far little or no information is available on 3D nonlinear, formulations of framed structures, equipped with nonlinear RWD element. Furthermore, proper physical and material modeling of RC frame building equipped with RWD is not seen. There is no report on nonlinear 3D RWD element compatible with frame structures.

Review of the literature also indicated lack of investigation on damage detection of RWD device during earthquake which play important role in structure safety. In depth study on multi support excitation effects on RC framed structures equipped with RWD are not seen. There no commercially available finite element code which utilize column, beam and nonlinear RWD element for dynamic inelastic analyses of frame and be capable to optimize the structural control system based on nonlinear response of framed building. The implementation of nonlinear RWD device in unsymmetrical 3D nonlinear frame structure under multi direction ground excitation is not well investigated and little information on 3-D effects i.e. torsion and irregular issues is available. The optimization of RWD element as energy dissipation device is not available in the literature. Hence the aim of this study is to pursue " The development of a general analytical model of RWD element which will be proposed for reinforced concrete and steel frame building structures ".

1.6 Objectives of study

The development of a general analytical model of rubber wall damper which will be proposed for placement in a non linear frame structure is the main goal of this study. Other detailed objectives which see the realization of the above aims includes the following:

- (1) To develop an effective passive damper from a high damping performance rubber and can be applied in frame structures which will be subjected to some earthquake excitation in its service lifespan
- (2) To develop and appraise capability of the developed numerical system of a passive rubber wall damper element from a high damping performance rubber comes along with the formulation of a suitable element constitutive model. This element numerical model shall be used as structural component for framed structures.
- (3) To develop a finite element method , verify the developed numerical model by performing experimental test on the passive rubber wall damper and computational procedure for nonlinear dynamic analysis of 3D frame structures equipped with rubber wall damper subjected to dynamic excitation.

1.7 Limitation of the present work Scope:

Limitations of the present works include:

- (i) Effects of soil-structure interaction are not considered.
- (ii) Effects of concrete confinements are not considered
- (iii) Rubber is a high damping performance material and here, it behaves within the elastic ranges material. The whole damper operates at a regular environment and temperature ranges of the equatorial country.

1.8 Proposed layout of the thesis

This thesis comes in five(5) chapters. The research hypothesis and the motivation for the current studies on the chosen problem is highlighted in Chapter 1. Other matters highlighted are the definition of the problem, a determinative statement on the problem, the study objectives along with the scope and the limits of the study.

Chapter 2, covers the review of the energy dissipation damper system, the properties of rubber, application of RWD in unsymmetrical, adjacent and parallel buildings, inelastic analysis of frame buildings developed procedure and computer program code are demonstrated and development of optimizing RWD through genetic algorithm has been reported and optimization of structural control system. The material used and methodology of present study is presented in Chapter 3. Development of 3D nonlinear RWD element, the modelling of inelastic frame element for beams and columns and constitutive model of both elements are illustrated. Development of finite element procedure for nonlinear analysis of frame structures with RWD are also presented in this chapter. the incremental iterative procedures for computation of nonlinear response of frame structures with RWD is illustrated through step by step procedure. Then the development special computer code based on the computational scheme has been presented. The validation of developed system and program code has been reported through analysis of some example of RC portal frames and comparisons of results with experimental results are presented. Chapter 4 deals with some applications of developed system for 2D and 3D, RC frame buildings. Linear and nonlinear response of structures are investigated. The effects of RWD properties on seismic response of buildings are evaluated and the application of RWD in an example of unsymmetrical buildings is reported. Further application of the RWD for connecting the adjacent buildings and coupling of parallel structure and the effects of different arrangement of RWD position on seismic response of structures are investigated through an example are presented in chapter 4. Report on performance of RWD as an energy dissipation device are discussed here using result from the experiment outcome of the RWD devices fitted to portal frame of steel and RC. Chapter 5 deals with the major conclusions drawn from the study carried out in the thesis together with the suggestions for further research in this area.

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