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Parametric study on equivalent damping ratio of different composite structural building systems

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Abstract. Structures consisting of concrete and steel parts, which are irregular in damping ratios are investigated. This investigation is a code-based seismic design of such structures. Several practical difficulties encountered, due to inherent differences in the nature of dynamic response of each part, and the different damping ratios of the two parts. These structures are irregular in damping ratios and have complex modes of vibration so that their analysis cannot be handled with the readily available commercial software. Therefore, this work aims to provide simple yet sufficiently accurate constant values of equivalent damping ratios applied to the whole structure for handling the damping irregularity of such structures. The results show that the equivalent damping ratio changes with the height of the building and the kind of the structural system, but it is constant for all accelerations values. Thus, available software SAP2000 applied for seismic analysis, design and the provisions of existing seismic codes. Finally, evaluation of different kinds of structural system used in this research to find the most energy dissipating one found by finding the best value of quality coefficient.

Keywords: mixed structure; SAP2000; quality coefficient; damping coefficient; equivalent damping coefficient; better seismic energy dissipating

1. Introduction

Composite member are emerging as efficient alternatives to traditional steel or reinforced-concrete systems is one type of mixed frame system consisting of reinforced concrete or composite columns and steel beams. Motivated by cost-effective use of materials, the general concept behind mixed systems is to use reinforced concrete in members with high compression and structural steel in flexural and tension members. Besides savings in material costs, mixed construction also offers significant structural advantages over all-steel welded or bolted construction for seismic design. For example, the steel beam can detailed to run continuously through the column and spliced in a less critical location, thereby overcoming problems associated with brittle fracture in welded joints and difficulties with bolted connections. In such cases, the composite connections contribute considerably to the savings offered by mixed construction over traditional steel and reinforced concrete systems. Sub assemblage tests confirm that, when carefully detailed, mixed systems possess adequate strength and ductility for seismic purposes

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(Parra-Montesinos and Wight 2001).

If the irregularly damped structure analyzed as is, without modification to the damping characteristics, the eignvalues arising are complex; therefore, they are not easily handling in an analysis and design process making use of commercial software. Villaverde (2008) proposes a method for using the complex modes of irregularly damped structures in combination with response spectra, in order to compute the maxima of the structural response.

The equations of motion studied in their state- space form and the modal characteristics properly handled in response spectrum analysis, in order to predict accelerations and displacements of the degrees of freedom of the structure with results close to the ones of time history analyses.

Current seismic provisions, such as those just mentioned, imply that mixed systems expected to behave similarly to counterpart systems of structural steel or reinforced concrete, the interactive effects between steel and reinforced concrete components on the seismic response not yet fully understood. The different components of a mixed system must possess adequate strength, stiffness, and ductility so that the structural system can perform as desired during a design seismic event. This can achieve by designing the steel and reinforced concrete components to interact together in an appropriate manner under all loading conditions. If the steel components are too flexible, their contribution to the energy dissipation capacity of the structure may not occur until after significant structural damage has occurred to the stiffer reinforced concrete components. Under such conditions, extensive nonstructural damage is possible.

On the other hand, overly stiff and strong reinforced-concrete components will attract large seismic forces and may impair the ductility and redundancy of the structure as a whole.

The assessment of existing design guidelines and the development of more rational guidelines for mixed frames require a thorough understanding of the inelastic seismic behaviour of these systems that can achieve through detailed inelastic analyses as shown in Fig. 1.

El-Tawil and Deierlein (2001) present the formulation of a beam-column element suitable for simulating the inelastic behaviour of three dimensional beam columns under combined axial load and biaxial bending. This paper describes calibration, implementation, and verification of the element model for steel, reinforced concrete, and encased composite members. The proposed modeling parameters are evaluated against published data based on tests and more refined analyses, and the paper concludes with a discussion of some areas in which the modeling tools are

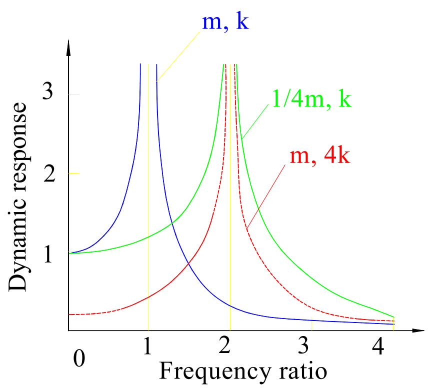


Fig. 1 Effect of mass and stiffness changes on dynamic response

being applied to investigate the seismic performance of mixed steel-concrete frames.

The degree of interaction of the composite beams affects significantly the overall stiffness and displacement/deformation demand. The amount of viscous damping used in finite element models of steel concrete composite (SCC) structures has a significant effect on their simulated seismic response. Only scarce information is available in appropriate values of viscous damping ratios to use in modeling SCC frame structures. The two values used in this study (i.e., 0.01 and 0.05) can be viewed as reasonable lower and upper bounds when energy dissipation due to material hysteretic behavior is already modeled explicitly.

The mass distribution between the steel beam and concrete slab components of composite beams is of minor importance with respect to the simulated response (both at the global and local levels) of SCC frame structures. Thus, for ordinary cases, detailed information on mass distribution between beam and slab is not required (Alessandro *et al*. 2007).

Classical composite beams with decks are use in steel structures since it requires simple construction, fewer person-hours, and no formwork. Furthermore, they showed good constructability (Viest 1997, Oehlers 1995). The slim floor, which developed to minimize story height (ECCS 1995, Mullett 1998), is now using in Europe. This structural system consists of fabricated steel beams and a deep deck. Therefore, the use of the slim floor in the construction of high-rise buildings has a limitation, but widely used.

The strength of the joint panel decreases as the girder flange is cutting in the panel zone because of the reduction of local bearing force on the steel flange. Herein, the strength satisfies the new criteria modifying the SRC standard of AIJ by taking the measured stress of hoops and the width of effective panel concrete into account. On the other hand, the ductility was quite large and it did not deteriorate at least up to a story drift of 0.05 radians, while critical shear deformation angle at the panel zone corresponding to this story drift state was 0.025 radians.

The high feasibility of the practical use of the proposed mixed structure system including the details of the girder to column connections developed here (Yukio *et al*. 1988).

Damping is usually present in earthquake engineering as a ratio or fraction of critical damping, called the damping ratio ξ, which is a property of the system material and independent of its mass and stiffness (Chopra 2005). Damping ratios commonly used in practice range between 1 and 10% of critical damping (Taranath 2005). Damping values depend on the construction materials, vibration amplitude, fundamental period and mode shapes, type of connections and the building configuration (Di Sarno and Elnashai 2008).

The iterative approach presented, holds high promise for obtaining very accurate responses to non-classically damped linear systems, within a few iteration (Firdaus and Ramin 1990).

Huang *et al.* (1996) consider a specific MDOF structure, with the lower degrees of freedom made of concrete and the upper ones made of steel. They propose a trial and error procedure where the structure is first model with the actual damping distribution and then several uniform damping ratios are tested. Finally, the damping ratio selected to represent the entire structure is the one that in a time history analysis gives the closest response to the actual one. Then, they appropriately represent the irregular structure with an equivalent 2-DOF structure, of which each degree of freedom has a damping ratio equal to the one of the corresponding parts of the complete structure. The assumption made is that the damping matrix of the 2-DOF structure is diagonal and thus an analytical estimation of the two modal damping ratios is possible.

Papageorgiou and Gantes (2011) proposed uniform equivalent damping ratios for structures with Rayleigh type damping, and with simpler damping configurations. The basis of these works is a trial and error process of potential uniform damping ratios in substitution of the actual damping distribution of the structure. Again, the ratio yielding the less erroneous response when compared with the response of the structure with the actual damping is select as the optimum one.

Wang *et al.* (2005) indicated that the equivalent-damping model could not simulate the structural system of an RC building with a steel tower atop it with acceptable accuracy. Instead, the non-proportional damping model should be use for this structural system. The result of the equivalent-damping model would be unsafe for the steel tower and too safe for the RC building at the same time. If there is no suitable software with non-proportional damping model for design, the inner force and displacement of the steel tower atop RC building should be amplify based on the calculated results obtained by using general structural software.

Veletsos and Ventura (1986) use the complex mode shape and complex frequency approach. They show that the corresponding transient displacement of a none classically damped multi-degree-of-freedom system can be expressed as a linear combination of displacements and the true relative velocities of a series of single degree-of-freedom systems subjected to similar excitations. Different approaches including modal superposition, complex mode shapes, direct integration, and weighted damping ratios have been compare in (Clough and Mojtahedi 1976) where direct integration has been indicate as the preferred method. A recursive step-by-step approach in the time domain, again requiring information about the complex mode shapes and complex frequencies found in (Singh and Ghafory-Ashtiany 1986, Spanos, 1988).

1.1 Damping coefficient

The equation of motion for a typical *N*-story building where each floor is represented by a rigid diaphragm with three DOFs (two are translational DOFs and the other one is rotational DOF) is in Eq. (1)

$$M\ddot{u} + C\dot{u} + Ku = -M\ddot{u}_g(t) \tag{1}$$

where the *M*, *C*, *K* corresponds to the mass, damping and stiffness matrices related to the deformation $u(t)$, ι is the influence vector, and $\ddot{u}_g(t)$ is the ground acceleration.

Rayleigh damping is viscous damping that is proportional to a linear combination of mass and stiffness. The damping matrix *C* calculated as

$$C = \mu M + \lambda K \tag{2}$$

where, *M* and *K* are the mass and stiffness matrices respectively and μ, λ are constants of proportionality.

Rayleigh damping does afford certain mathematical conveniences and is widely used to model internal structural damping. One of the less attractive features of Rayleigh damping is that the achievers damping ratio varies as the response frequency varies. The stiffness proportional term contributes damping that is linearly proportional to response frequency and mass proportional term contributes damping that is inversely proportional to response frequency. Mathematically, these frequency dependencies seen in the formula for damping ratio as

$$\xi = \pi(\mu / f + \lambda f) \tag{3}$$

where, *f* is the response frequency.

For composite structure, the equation of damping given by

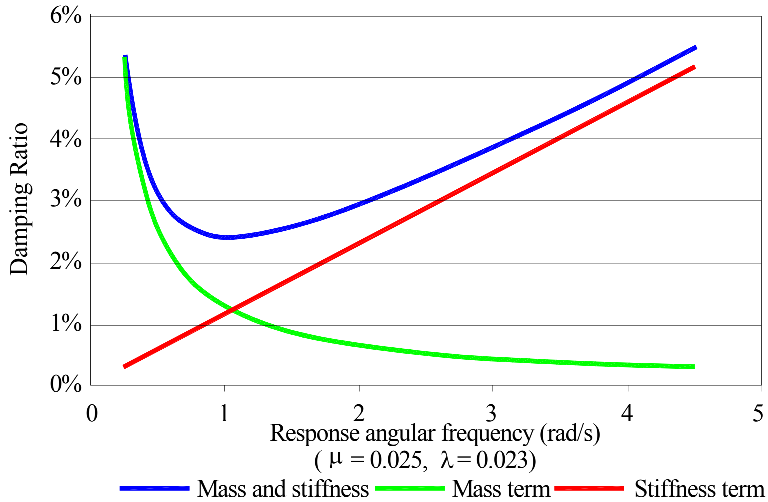


Fig. 2 Variation of damping ratio with frequency

$$C = \mu_s M_s + \lambda_s K_s + \mu_c M_c + \lambda_c K_c \tag{4}$$

where; μ_s, λ_s, μ_c, λ_c are constants of proportionality, and M, K are the mass and stiffness matrices for steel and concrete respectively.

The plot below Fig. 2 illustrates how the separate mass and stiffness damping terms contribute to the overall damping ratio:

SAP2000 allows users to either specify coefficients μ and λ directly, or in terms of the critical-damping ratio either at two different frequencies, *f (Hz)*, or at two different periods, *T* (sec).

When damping for both frequencies is set to an equal value, the conditions associated with the proportionality factors simplify as Eq. (5) (Wilson 2004)

$$\xi_i = \xi_j = \xi \quad therefore \quad \mu = \frac{2\xi}{\omega_i + \omega_j} \quad and \quad \lambda = \omega_i \omega_j \mu \tag{5}$$

For composite structures, the proportional coefficients are as Eq. (6)

$$\mu_s = \frac{2\xi}{\omega_i + \omega_j}, \; \lambda_s = \omega_i \omega_j \mu_s \quad and \quad \mu_c = \frac{2\xi}{\omega_i + \omega_j}, \; \lambda_c = \omega_i \omega_j \mu_c \tag{6}$$

The setting of constant hysteretic damping with both mass- and stiffness-proportional damping set to 0.05 is not the same as setting a constant modal damping of 0.05. During steady-state analysis, CSI Software uses hysteretic damping. However, the question fielded concerns modal damping. As stated in the SAP2000 Analysis Reference Manual, (CSI 2009) for steady-state and power-spectral-density cases, the hysteretic damping matrix is calculated as a linear combination of the stiffness matrix, scaled by coefficient d_k, and the mass matrix, scaled by coefficient d_m. To approximate modal damping in terms of hysteretic damping, d_m can be set to zero and d_k can be calculated using the relation $d_k(\omega) = 2\, d(\omega)$, where $d(\omega)$ is the modal damping ratio. For example, if a constant 5% modal damping is used for all modes, the equivalent hysteretic damping value is a constant $d_k(\omega) = 0.10$. For each mode, this leads to approximately the same level of response at resonance.

Using the natural frequency of the simple harmonic oscillator $\omega_0 = \sqrt{k/m}$ and the definition of the damping ratio above, we can rewrite this as Eq. (7)

$$\frac{d^2x}{dt^2} + 2\xi\omega_0 \frac{dx}{dt} + \omega_0^2 x = 0 \tag{7}$$

The solution of this equation is

$$x(t) = C\, e^{st} \tag{8}$$

Where, C and s are both complex constants. That approach assumes a solution that is oscillatory and/or decaying exponentially. Using it in the *ODE* gives a condition on the frequency of the damped oscillations, as Eq. (9)

$$S = -\omega_0(\xi \pm \sqrt{\xi^2} - 1) \tag{9}$$

Depending on the magnitude of damping, a damped system can be under-damped, critical-damped or over-damped. The critical damping coefficient determined by the system's mass and spring constant. Under critical damping, the damping ratio is unity. Critical damping separates non-oscillatory motion from oscillatory motion. When the damping ratio is greater than one, which called over-damping, the system does not oscillate. For a damping ratio less than one, which called under-damping, the system oscillates with decaying magnitude, as shown in the figure below. For most physical system, damping ratios are less than one. Actually, most physical systems have a damping ratio less than 0.1. With damping in the free vibration system, the mass always restores its equilibrium position even it is disturbed. The greater the damping, the less time it takes to restore its equilibrium position. Therefore, in most cases, adequate damping is desirable.

The context of resonators, Q (quality coefficient) is defined in terms of the ratio of the energy stored in the resonator to the energy supplied by a generator, per cycle, to keep signal amplitude constant, at a frequency (the resonant frequency), f_r, where the stored energy is constant with time as Eq. (10)

$$Q = 2\pi \times \frac{\textit{Energy Stored}}{\textit{Energy dissipated per cycle}} = 2\pi f_r \times \frac{\textit{Engery Stored}}{\textit{Power Loss}} \tag{10}$$

- A unity gain Sallen–Key filter topology with equivalent capacitors and equivalent resistors is critically damped (i.e., $Q = 1/2$).
- A second order Butterworth filter (i.e., continuous-time filter with the flattest pass band frequency response) has an under damped $Q = 1/\sqrt{2}$ (William 2006)
- A Bessel filter (i.e., continuous-time filter with flattest group delay) has an under damped $Q = 1/\sqrt{3}$.

The factors Q, damping ratio ζ, and exponential decay rate α are related such that (William

2006) given in Eq. (11)

$$\xi = 1/2Q = \alpha/\omega_0 \tag{11}$$

When a second-order system has $\xi < 1$ (that is, when the system is under-damped), it has two complex conjugate poles that each has a real part of α; that is, the decay rate parameter α represents the rate of exponential decay of the oscillations. A lower damping ratio implies a lower decay rate, and so much under-damped systems oscillate for long times [For example, a high quality tuning fork, which has a very low damping ratio, has an oscillation that lasts a long time, decaying very slowly after being struck by a hammer.]

All methods investigated in the literature and proposed by design codes grouped in two categories. In the first, usually mentioned as the decoupled approach, the two parts of the structure are modeled and analyzed separately, thus avoiding the damping irregularity, but ignoring the interaction of the two parts. In the second, known as the coupled approach, the structure modeled as a whole, thus taking interaction of the two parts into account, but having to confront the issue of damping irregularity. In the decoupled analysis procedure, the structure is decomposing into its two separate parts, and each one analyzed separately. The primary structure is excited with the ground motion at its base and its response in terms of total accelerations at all levels obtained. Then, the substructure's response at the support level of the superstructure used as excitation to the latter, and in turn, its response obtained. The advantage of the decoupled procedure is that the irregularities arising when the structure analyzed as a whole overcome, since each part, when studied on its own, is regular. Moreover, the decoupling of irregular structures of the types studied in this work is convenient for everyday design practice, since often-different teams are responsible for the analysis and design of the concrete and steel parts of the structures. One disadvantage is that this approach may lead to significant inaccuracies, as in each of the two separate analyses the interaction of the two parts is neglect. In addition, the cross-correlation between modal responses is neglect, which may be important, especially in cases where the Eigen frequencies of the two parts are closely related.

2. Objective and methodology

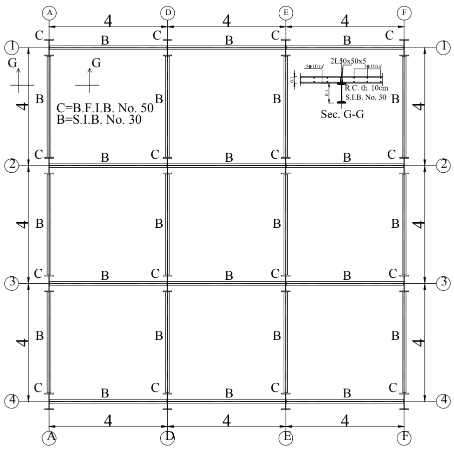
After 12 October 1992 earthquake in Cairo, the need for safe structures at reasonable cost has been growing, and a new trend of design has been taking place.

The aim of this paper is to propose equivalent uniform damping ratios and using them in the analysis of irregularly damped linear concrete/steel structures, replacing the actual damping distribution, thus enabling the use of existing commercial software. It should not be overlooked that equivalent damping ratio is actually a concept with limited physical meaning, and is only a convenient way to represent energy dissipation of the irregular structure. Nevertheless, the scope is to provide an engineering friendly means of calculating the response of such structures that overcomes the practical analysis difficulties.

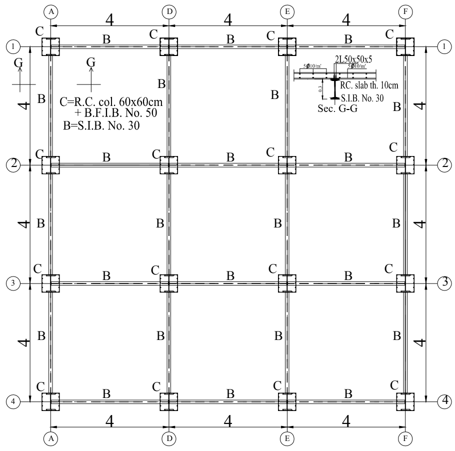
Different applications and conditions of the structures necessitate using concrete and steel hybrid systems in some cases. One or more transitional storey used in hybrid structures for better transition of lateral and gravity forces. The available design regulations have not presented a method for determining the damping of these structural systems, which can cause some problems in designing these structures. Validation of the proposed method with exact method and the former methods showed the high accuracy of the proposed method.

For a wide range of dynamic characteristics arbitrarily selected damping ratios are tested and the ones that yield less error, as far as the response characteristics are concerned, are selected as the most suitable to be used as equivalent uniform ones.

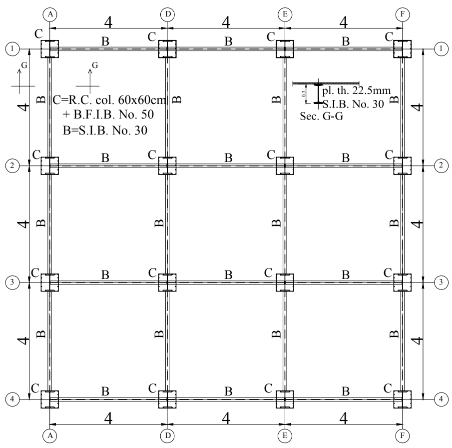
For this purpose, seven kinds of structural systems tested with 20-storey height each floor is 3 m (60 m total height from ground level). The first type is a mixed with two transitions storey (the columns of these storey are a composite section and steel graders and plates as shown in Fig. 3(a)) in addition, the first two storeies are all R.C. (Fig. 3(e) and the above 16th storey are all steels (Fig. 3(a)) as the description in Table 1. The second type is a mixed with one transition storey (the columns of this storey is a composite section and steel graders and plates as shown in Fig. 3(c)) moreover, the first two storeies are all R.C. (Fig. 3(e)) in addition, the above 17 storeies are all steels (Fig. 3(a)) as the description in Table 1. The third type is a mixed on the first two storeies is all R.C. (Fig. 3(e) and the above 18 storeies are all steels (Fig. 3(d)) moreover, as the description in Table 1. Fourth type all 19th storey are steel (Fig. 3(a)) in addition, the 20th floor is R.C. with a composite column (Fig. 3(f)) and the above 17th storey are all steels (Fig. 3(a)) as the description in



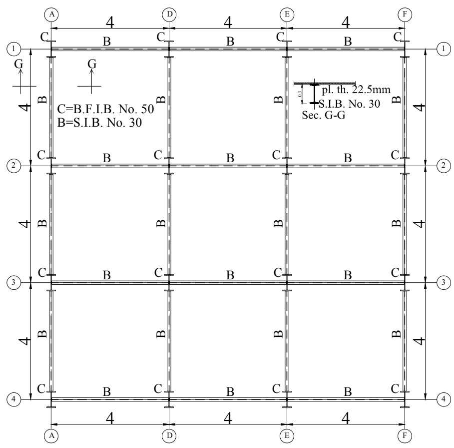
(a) Steel girders and R.C. slab + steel columns



(b) Steel girders and R.C. slab + Composite columns

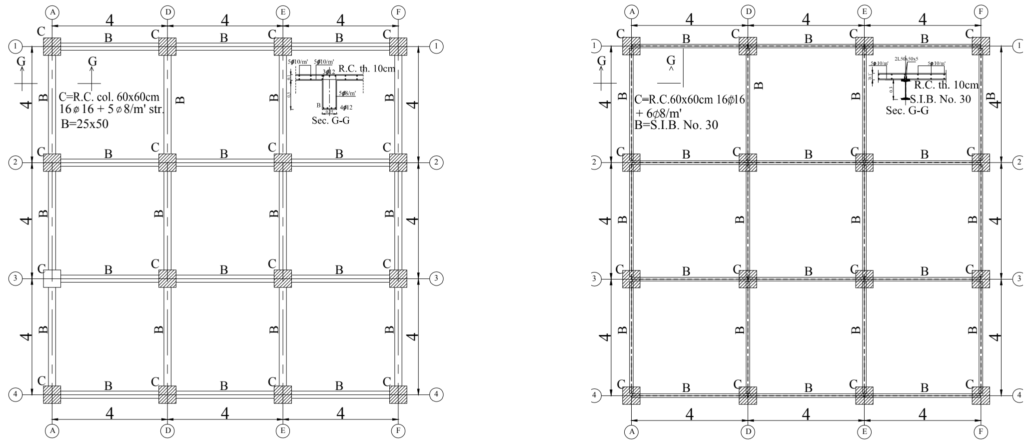


(c) Steel girders and plates + composite columns



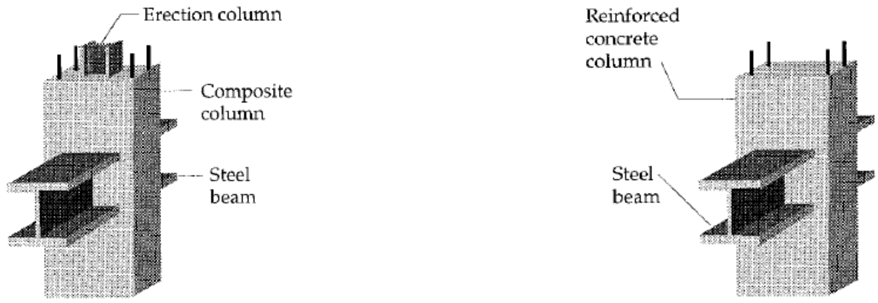
(d) Steel girders and plates + steel columns

Fig. 3 Continued



(e) R.C. Floor (slab + beam + column) (f) Steel girders and R.C. slab + composite columns

Fig. 3 Typical structural floor planes of different kinds of structural system



(a) Steel beam passing through composite column (transitional column)

(b) Steel beam passing through reinforced concrete column

Fig. 4 Typical structural column grader joint

Table 1. Fifth type mixed in the plane and R.C. columns as shown in Fig. 3(f) as description in Table 1. The sixth type mixed in plan with transition columns (the columns of these storeies are composite sections and steel girders and R.C. slabs as shown in Fig. 3(b)) moreover, as the description in Table 1. The final kind is steel column + R.C. slabs all the 20 t storeies are with structural planes as shown in Fig. 3(a).

Fig. 4 shows the types of connection between columns and steel girders in both cases of structural system, Fig. 4(a) shows the steel grader connected to a composite section column, and Fig. 4(b) illustrates a grader connected to a reinforced concrete column.

Table 1 shows shortcuts of the tested structure.

To find the equivalents damping ratios of the previous kinds of structural system fist the values of α, and μ (proportional values of damping) applying in SAP2000 for steel and concrete then, the response of each kind (top displacements and maximum base shear) is represented. Different values of constant damping ratios applied for all kinds and the response of models compared to give the range of damping ratio. The previous work done for different values of peak ground

Table 1 Description of the using models

No	Symbol	Description
1	Mixed 2 transitions	First two storey are R.C. and two transition storey and 16th steel storey
2	Mixed one transition	First two storey are R.C. and one transition storey and 17th steel storey
3	Mixed no transition	First two storey are R.C. and 18th steel storey
4	Steel with R.C. top storey	First 19th storey are steel storey and final storey (20th storey) R.C. storey
5	Mixed in plane and R.C. col.	All floor plans are steel graders and plates and R.C. columns
6	Mixed in plane and transition col.	All floor plans are steel graders and plates and composite R.C., steel columns
7	Steel col. +R. C. slab	All floor plans are steel girders and R.C. slabs and steel columns

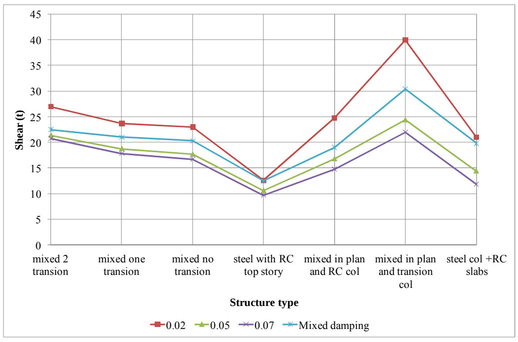
acceleration (PGA) (1 g, 0.5 g, 0.3 g, 0.25 g, 0.2 g and 0.15 g) to show the stability of the constant damping ratios for all models. The model mixed with no transition storey taken as a study case to evaluate the constant damping ratio for the different height model and PGA values. The values of damping ratios of steel elements in the mixed structures was taken equal to 2%, and for reinforced concrete elements equal to 5%, and for transition elements (composite columns) equal to 7%, these values was applied as constant damping ratios for all kinds of structural systems were tested. The investigation is restricted to the case that both parts are in the elastic plastic range.

3. Results and discussion

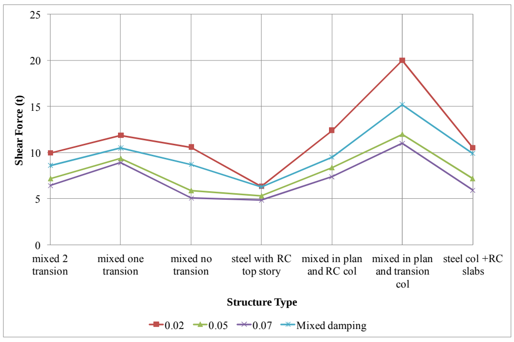
A 20th storey models were tested to find equivalent damping ratios for different structural systems (mixed structure) with total height 60m from ground level. All kinds of structural system are exposure to a different PGA values.

Fig. 5 shows the response of the different kinds of structural systems for top displacement and maximum base shear. Fig. 5(a) illustrates the maximum base shear of different kind of structural systems for different PGA. As shown in figure the values of base shear for all structures with mixed damping ratios (damping ratio for every kind of structural elements i.e., reinforced concrete 5%, steel 2%, and transition 7%) lies between the constant damping ratios for all the structure (2% and 5%) and this phenomena appear in all PGA values. Base shear values for mixed one transition storey show a lower value with respect to all kinds of structural system, because of the transition forces from different parts of the structure (top steel and bottom R.C.), damping ratio for steel with an RC top story system for all PGA values nearly equal to 2%, and mixed in plane and transition columns constant damping ratio equals to nearly 3.3% (high values), this because the high value of damping ratio of transition elements (equal to 7%). The first three kinds of structural systems show a reduction in the values of base shear force.

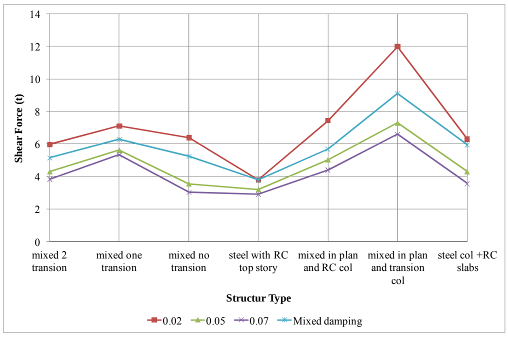
Fig. 5(b) shows top displacement of different kinds of structural systems for different values of the PGA. The 2nd, 3rd, 4th, 5th, and 6th structural systems were nearly equal in different PGA cases. The reduction of top displacement for first three structural system kinds was specified specially for the PGA equals to 1 g. The mixed with one transition storey structural system shows a very high response in reduction of top displacement for all PGA values, on the contrary steel columns and



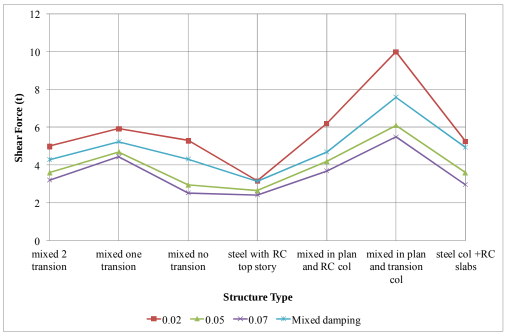
(a) PGA = 1 g



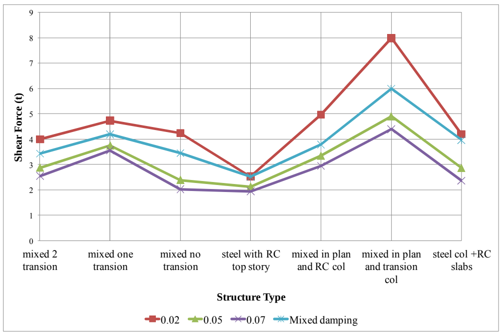
(b) PGA = 0.5 g



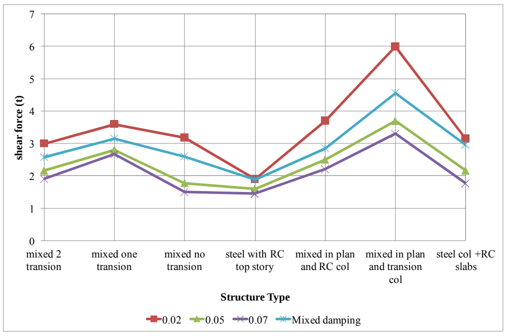
(C) PGA = 0.3 g



(d) PGA = 0.25 g

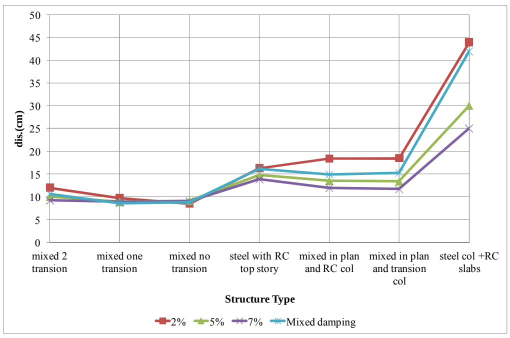


(e) PGA = 0.2 g

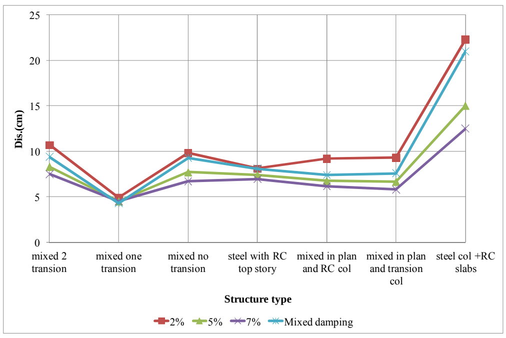


(f) PGA = 0.15 g

(a) Base shear force

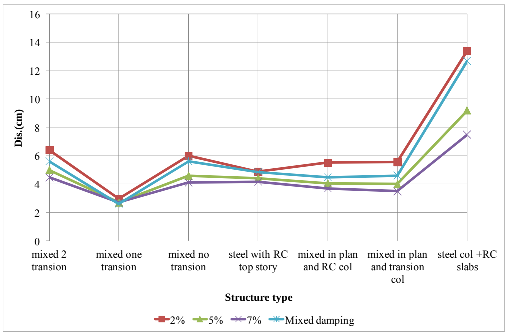


(i) PGA = 1 g

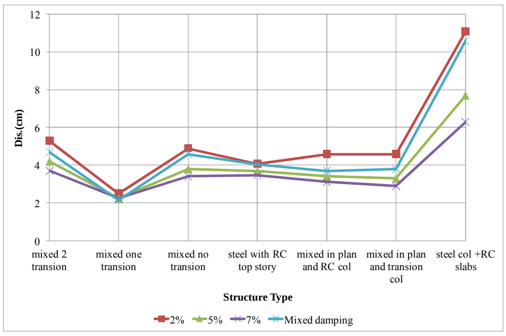


(ii) PGA = 0.5 g

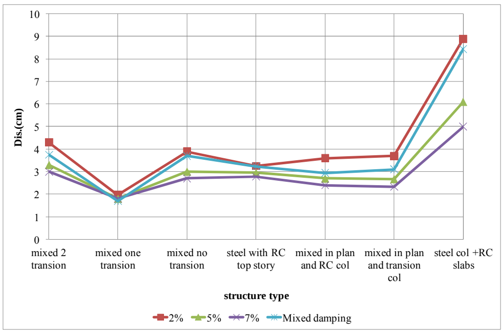
Fig. 5 Continued



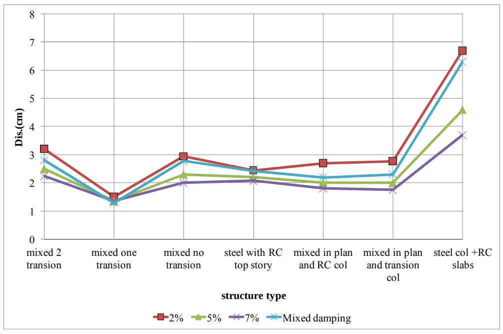
(iii) PGA = 0.3 g



(iv) PGA = 0.25 g



(v) PGA = 0.2 g



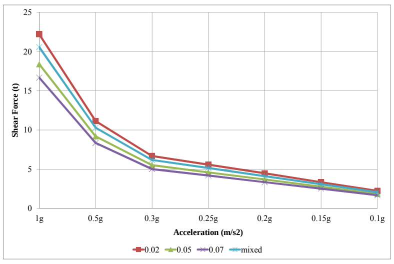
(vi) PGA = 0.15 g

(b) Top displacment

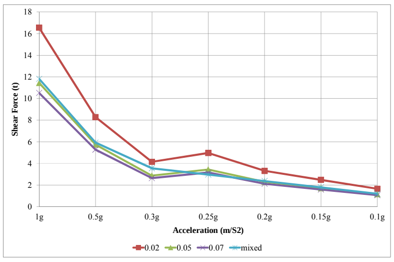
Fig. 5 The response of different kinds of structural systems subject to different earthquake accelerations

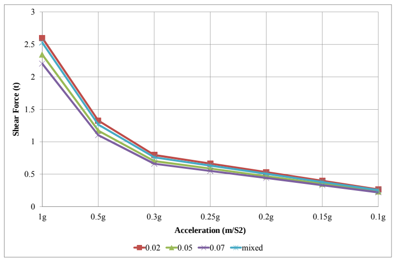
R.C. slab shows a higher value of top displacement than all the structural systems kinds.

Fig. 6 shows the response of the mixed structural system (the first two storey are R.C. and the 18th storey are steel columns and plates) for maximum base shear force and top displacement for different PGA and the heights of the model. Fig. 6(a) shows maximum base shear for the model, values of base shear with a mixed damping ratio lies between 2% and 5% constant damping ratios applied all over the model for different values of the PGA. This phenomenon repeated in different heights (20th, 6th, and 2 storey). Fig. 6(b) shows maximum top displacement for the model, values of top displacement with a mixed damping ratio lies between 2% and 5% constant damping ratios applied all over the model for different values of the *PGA*. This phenomenon repeated in different heights (20th, 6th, and 2 storey).



(i) Twenty storeies mixed structure

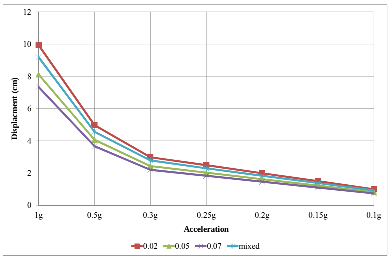




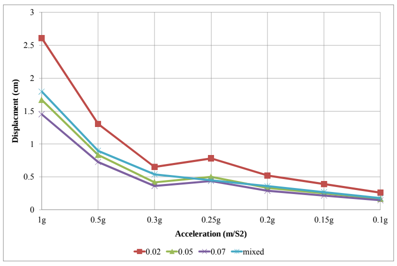
(ii)Six storeies mixed structure

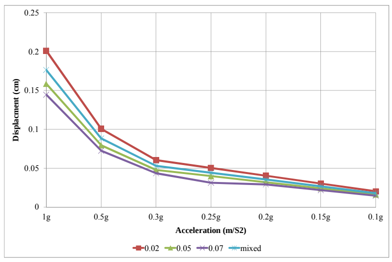
(iii)Two storeies mixed structure

(a) Base shear force



(iv)Twenty storeies mixed structure





(v) Six storeies mixed structure

(vi)Two storeies mixed structure

(b) Top displacment

Fig. 6 The response mixed no structural system subject to different earthquake accelerations

Table 2 Quality Coefficient of different structural systems

No. of storey	*Q*(quality coefficient)		
	6th	12th	20th
mixed	0.16	0.17	0.20
mixed with 1transition	0.11	0.13	0.14
mixed with 2 transition	0.12	0.14	0.18
steel col +RC slab	0.21	0.21	0.21
RC col+mixed steel	0.15	0.15	0.14
transition col+mixed steel	0.14	0.15	0.14
steel col +top RC	0.21	0.24	0.25

Table 3 Equivalent damping ratios for the used structural systems

No. of storeies	6th	12th	20th
Mixed	3.12	3.025	2.555
Mixed with 1transition	4.61	4	3.5775
Mixed with 2 transition	4.15	3.5	2.85
Steel col. +RC slab	2.34	2.36	2.4
RC col. + mixed steel	3.41	3.42	3.575
Transition col. + mixed steel	3.6	3.355	3.58
Steel col. + top RC	2.41	2.0888	2.022

Table 2 represents the quality coefficients of different kinds of structural systems in different heights of the structures (6^{th}, 12^{th}, and 20^{th} storey). From table the mixed with one transition storey in three selective heights show the lowest values of quality coefficient than the different kinds of tested structural systems this indicates that this system can be a good solution for of the seismic forces resistance.

4. Conclusions

The dynamic response of elastic-plastic structures consisting of two parts with different damping ratios, a part made of concrete with 5% damping ratio, a part made of steel with 2% damping ratio, and transition part with 7% is investigated. Such structures are irregularly damping and have complex modes of vibration, so that their analysis cannot be handled with the readily available commercial software. In this work, a methodology is proposed for their dynamic analysis that makes use of semi-empirically obtained equivalent uniform damping ratios, and its efficiency is tested in a model. The ground excitation used is Elcentro in resonance with the first mode. The equivalent damping ratios are tested on seismic records with satisfactory results regarding the error in the response estimation. These results can be applied for MDOF irregular structures, using the first mode characteristics of each part, and then estimating the equivalent damping ratios using the proposed plots. The efficiency of these ratios will be tested on a multi-storey irregular concrete/steel frame structure subjected to seismic input. The results obtained indicate that the use of the equivalent damping ratio yields results that are similar to the ones obtained by the actual damping distribution and provide a much better approximation than the case where the conservative overall ratio of 2% is used. It noted that the calculation of equivalent damping ratios for irregular structures is case dependent; therefore, the proposed method should be restricted to elastic structures, without adding damping devices.

This study indicates that mixed steel and concrete constructions are very useful in seismic resistant design. However, careful evaluation of the strength and ductility of the connections between the steel and concrete must be done. Rigid concrete frame connections are desirable, because they produce greater stiffness, smaller deflections, and small member sizes. These connections designed to develop rotational ductility within the bolted connection.

Embedded steel columns provide a second useful method for connecting steel frames and concrete walls.

This paper also, indicates several areas, which require further study before the seismic behaviour of mixed structures fully understood. Additional tests are needed to understand the effect of cyclic loading on the strength and ductility of both types of connections. Further studies are needed to determine the transfer mechanism for load and moments in embedded steel columns to the concrete. Finally, analytical models, which describe this connection behaviour, would be useful in the analysis of the whole structure since connection behaviour has a significant effect upon the strength stiffness and ductility of mixed structures.

The importance of this study concluded in finding the equivalent-damping ratio for some kinds

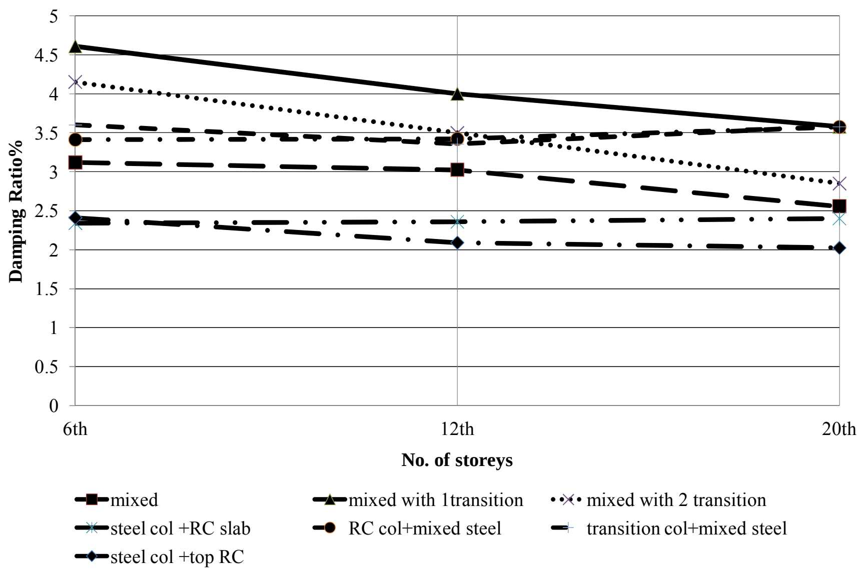


Fig. 7 Equavelent damping ratio values of some kinds of structural system with different heights

of structural systems and find which of the systems can be more useful in earthquake resistance. Fig. 7 illustrates the values of damping ratios that can used as constant damping ratio for whole structure building for the dynamic analysis covering different heights and different kind of structural systems. The mixed structure system with one transition storey for different heights showed a good resistance for earthquake forces as shown in Fig. 7.

Quality coefficients give good indicate of the performance of the structure systems subjected to earthquake.

Future studies are needed especially for mixed systems with transition story by shaking table test to emphasize the obtained results in this paper.

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