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The Timber Floor Seismic Design by Means Finite Element Method

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Abstract

To improve accuracy results of numerical analysis, the finite element method software needs to use appropriately with considering accurate input data. Among several factors in realistic and economical seismic structural design, the damping ratio needs to be investigated as a calculated and input data in numerical analysis. In the present study, the effect of accurate damping ratio on timber floor seismic design has numerically been examined. The 6 first modes from a series of eigenvalues were selected to calculate natural frequency and damping ratio. The seismic results with and without applied calculated damping ratio were compared. The strain, displacement, and seismic load response are interpreted. The numerical analysis results were showed that the higher nonlinear displacement occurs in timber floor when the damping ratio was modified in numerical modeling. It was found that the floor seismic design is more critical compared to a column in select accurate damping ratio. The damping ratio has highly effect on timber floor seismic design.

Keywords: Timber Floor; Seismic Design; Damping Ratio; Strain; Displacement.

1. Introduction

The floor of a structure is the critical part in seismic design. The floor plays an important role in load transferring and controlling seismic strain energy during developing displacement and nonlinear deformation. The several structural collapse start from the floor and collapse extended with unbalancing transferring load mechanism in structure through development strong inertial interaction and accelerates increasing structural elements eccentricity, finally results in fast structural collapse. The floor reacts with deformation and displacement when it is under loads, and unallowable displacement and deformation depend on floor geometry, mechanical properties of materials and nature of applied. However, the select accurate or near accurate damping ratio is very essential in a timber seismic design with simulate strain energy interaction mechanism. The floor of timber building have been investigated and the enhancement of seismic resistance of timber structure was studied [1-3]. There is a report on the improvement of the seismic resistance of historical industrial timber buildings [4]. Several research were reported on timber beam and column to study displacement, strain energy and seismic load sharing [5-7].

In the present study, based on elasticity method is applied in numerical analysis, it aims to enhance the timber structure seismic design with realize strain energy concept. However, in the literature, the effects of seismic loading on timber frame has been reported, and the timber seismic response is analyzed [8], and on the other hand to minimize error in solving elasticity problem several investigations were described [9-10], and it has been observed that the concept of strain energy and damage under different strain rate have been reported in the literature [11-14].

The tall mass-timber buildings subjected to wind loads [15], the post-tensioned rocking timber wall systems [16], the timber-framed house subjected to the wind loading [17], seismic resisting of timber structures [18] have been

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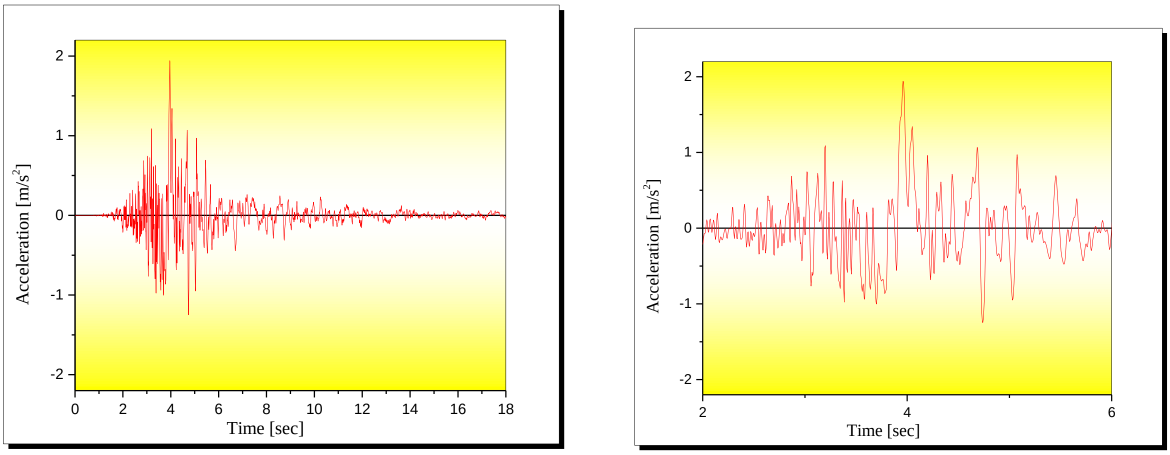
investigated and on the other hand the residual stress redistribution has numerically been reported [19]. In respect to available literature report it is essential to apply the concept of strain energy in timber floor seismic design with attention to seismic response of timber frame in apply elasticity concept in numerical simulation, this process requires to perform with consider model geometry and the mechanical properties of materials. According to small displacement theory, the strain and displacement a timber floor are need to analyze. The collaboration between damping ratio and strain energy at the floor of timber structure has not been reported in the literature by means finite element software ABAQUS, and significant research works related to timber beam are required more research extension. Due to strain energy function in structural collapse occurrence, the investigation on stain energy with variable damping ratio is a technique for enhancing timber beam seismic resistance. In the present study, the ABAQUS used to depict strain energy exhibit in the model. In the present study, near-fault ground motions are applied to the model. The suitable number of eigenvalues for calculate natural frequency and damping ratio when the model is subjected to forcing frequency examined. The realistic strain, displacement and seismic load response of the timber floor were obtained, and the column strain, column lateral displacement, and timber frame acceleration load response have numerically been analyzed. The seismic response of timber floor with timber column have been compared for withdrawing a conclusion in view of seismic design. The results of numerical analysis have been compared with the literature report.

2. Modeling and Floor Seismic Response

After applied forcing frequency on the timber structure model, the 6 first modes from a series of eigenvalues were selected to calculate natural frequency and damping ratio. The number of eigenvalues to calculate natural frequency when forcing frequency is applied to the model is a critical part of the seismic design to obtain a suitable damping ratio and applied to the model in numerical simulation. The seismic results with and without applied calculated damping ratio have been compared. The damping ratio was calculated by means complex frequency method, it is output from state-space models and finite element method models. In the second steps, the near-fault ground motions extracted from the literature and forcing frequency were applied to the model simultaneously. The seismic response of timber floor with timber column have been compared for withdrawing a conclusion in view of timber structure seismic design. The boundary condition with the fixed rigid base of the timber structure model for analysis timber structure seismic response has been modelled by means ABAQUS. The suitable damping ratio significantly effects in numerical results accuracy. The mechanical properties are used in the numerical analysis shown in table 1. Figure 1 (a) shows, the accelerated times histories, and Figure 1 (b) describes the zoomed critical part of acceleration time history which is applied in the numerical analysis. The simple one span timber frame has been selected in the numerical analysis. Figure 2 shows the timber frame is subjected to seismic loading in the numerical analysis. Figure 2 shows the research methodology applied in the present study. In the first step the geometry of the timber frame was designed, with suitable selection mechanical properties for timber material, second steps is performed with apply forcing frequency for calculate damping ratio of the timber frame model, third steps is executed with apply seismic load on the model. The steps forth is been done to extract numerical results, steps fifth is performed to draw graphs for interpretation of the numerical analysis results, and sixth steps which is final steps made to withdraw conclusion.

Table 1. Timber mechanical properties

Materials	Modulus elasticity, E (MPa)	Poisson's ratio, ν	Unit weight, γ kg/m^3
Timber	6500	0.3	580



(a) Before zoomed **(b) after zoomed**

Figure 1. Acceleration time history

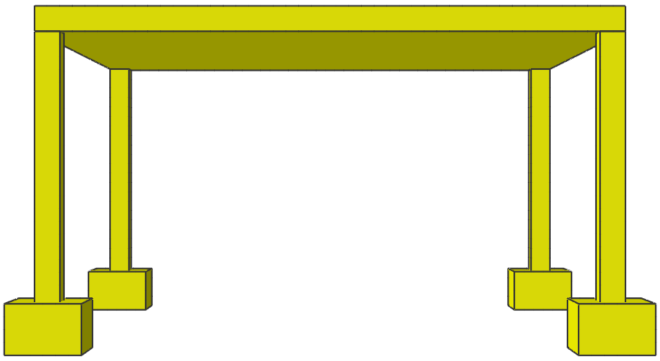


Figure 2. Timber frame model

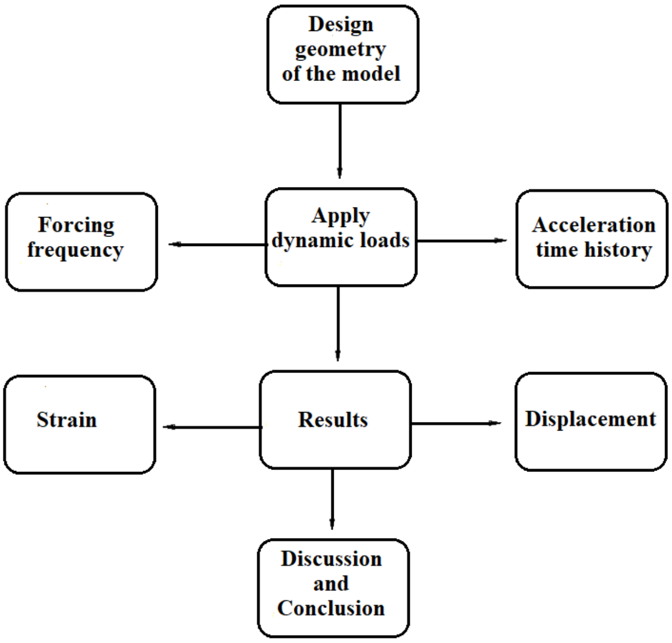


Figure 2. The research methodology

3. Discussion for Explaining Numerical Analysis Results

The damping ratio function as a data input in finite element software in modification strain, vertical displacement and seismic response of the timber structure floor and column were studied and results show in Figures 4 to 13. In order to compare the efficiency of the numerical analysis in all models, the seismic response, strain and displacement are considered with respect to the applied damping ratio. The damping ratio has been calculated based on forcing frequency and geometry of the timber frame. Fundamental frequency period for the timber frame is obtained as six first modes of frequency period corresponding to the timber frame vibration at six important directions. The average curve with all six modes frequency of simulated seismic excitation used to calculate damping ratio. The numerical analysis results show that the strain energy paths changes with alter damping ratio and lead to modify the inertial interaction and strain energy dissipation, consequently release strain energy governs the nonlinear deformation of timber floor response and it results in develops vertical displacements. The floor and column have two different seismic response. The internal inertia forces interaction more has been effective in the seismic response, strain and displacement analysis. The timber frame failure pattern is changes with respect to the internal inertia forces interaction, and it causes modification lateral displacements mechanism. The seismic excitation mechanism directly influence on the structural elements damage intensity. However, the accurate calculation damping ratio significantly effects on enhance seismic structural design quality. In the present study, according to the Figures 4 to 7 have been revealed that when the damping ratio was calculated by means complex frequency method, and it applied in finite element method analysis, the floor of timber structure has more vertical displacement, but the nonlinear deformation of the floor has been reduced with moderation seismic load response.

The nonlinear deformation of the structure is mode based on changing nature of applied seismic loading. The degree of plastic deformation significantly varied in associate to the nature of applied seismic loading for each numerical simulation. The degree of plastic deformation, strain energy and flexibility of the timber frame more realistically have been obtained with apply damping ratio in the numerical analysis. The concentration strain energy density is modified and displacements of the floor are changed while the seismic response is representative of the frame vibration and damage expectation also altered. The nonlinear deformation of timber floor response has a direct relationship with the damping ratio calculation accuracy and apply proper theoretical concept. The allowable displacement and deformation of timber floor are higher than concrete and it needs to consider in seismic design, in order to have a floor with a higher level of flexibility. The flexibility of a floor causes in delay floor collapse even with apply high level of near-fault ground motions applied on the structure due to occurrence a strong earthquake, or even an earthquake with a moderate magnitude but a high level of tolerance. The high level of tolerance an earthquake made fast fatigue in a structural element especially in the floor. The nature of an earthquake governs nonlinear displacement and deformation of the structural element, and due to excess inertial interaction and increasing fast releasing strain energy floor displacement appeared in different shapes. Figures 6 and 7 show moderation seismic acceleration load response with higher vertical displacement, it means the vibration has been significantly reduced. The fast fatigue and hysteretic damping accelerates the internal and external timber frame deformations. The plastic deformation and damage are predictable with realize high quality of frame seismic response, with is depicted in the Figures 6 and 7. According to those are reported in the literation the shape of a structural element significantly influences to load seismic response [20, 21]. The accurate select damping ratio changes strain energy paths. The realistic strain, displacement, and seismic load response have been moderated and leads to design safe and economical timber design. The complex frequency method gives economical results in using finite element method for timber floor design. The damping ratio governs the floor displacement while has no significant effect on column lateral displacement.

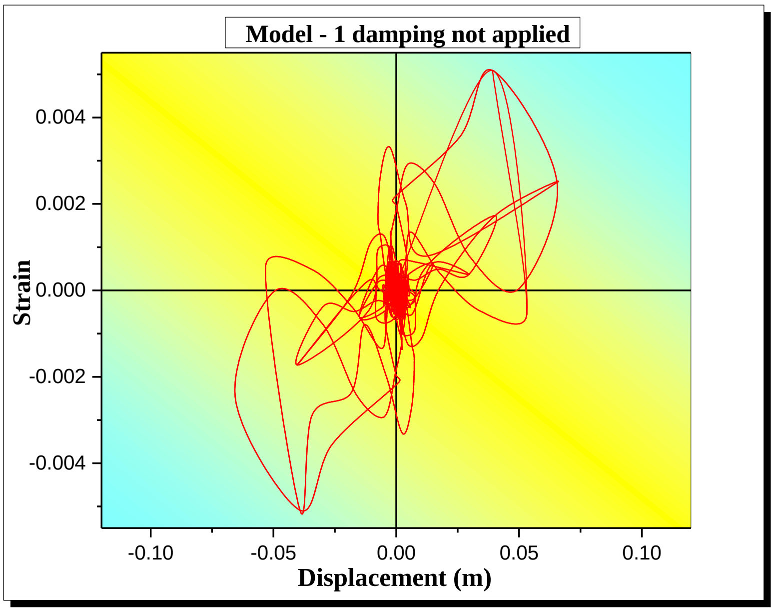


Figure 4. Strain-displacement of the floor without applied damping ratio

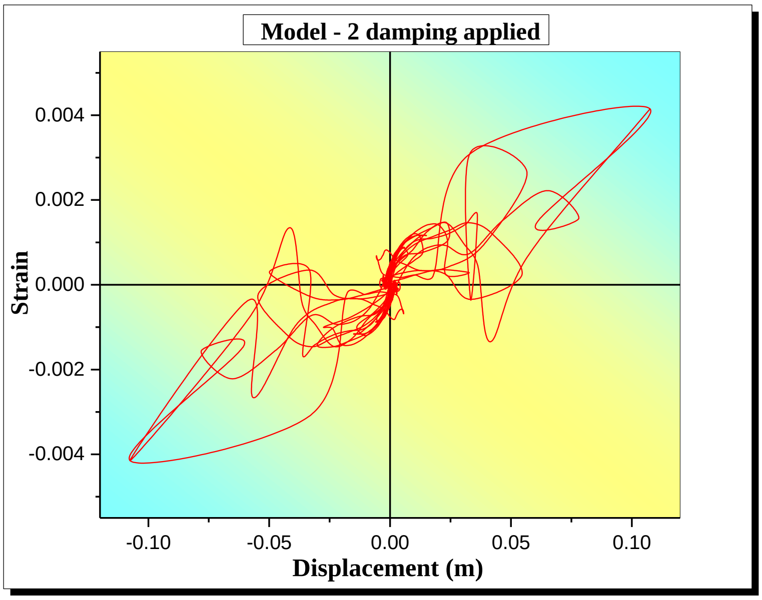


Figure 5. Strain-displacement of the floor with applied calculated damping ratio

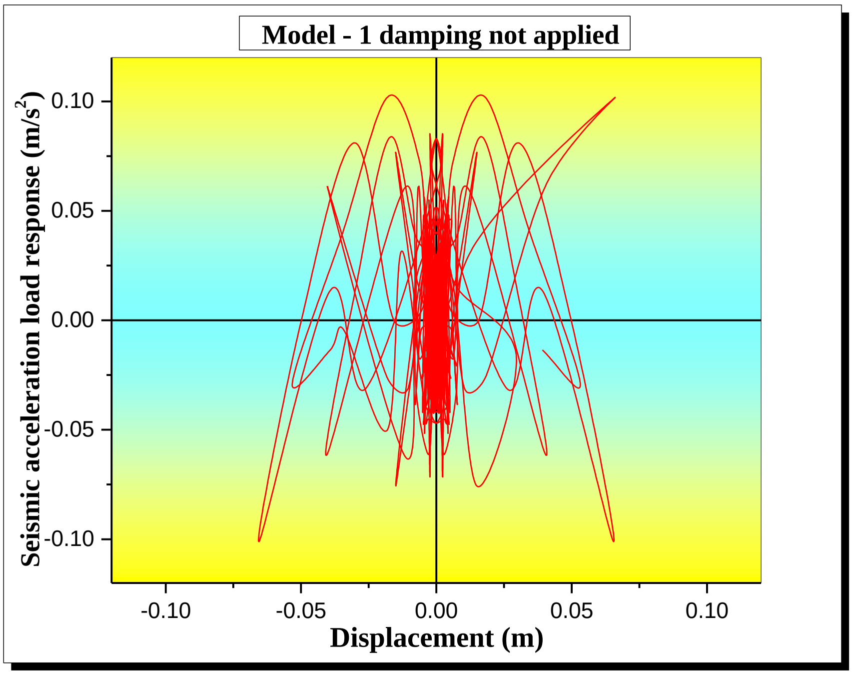


Figure 6. Seismic response-displacement of the floor without applied damping ratio

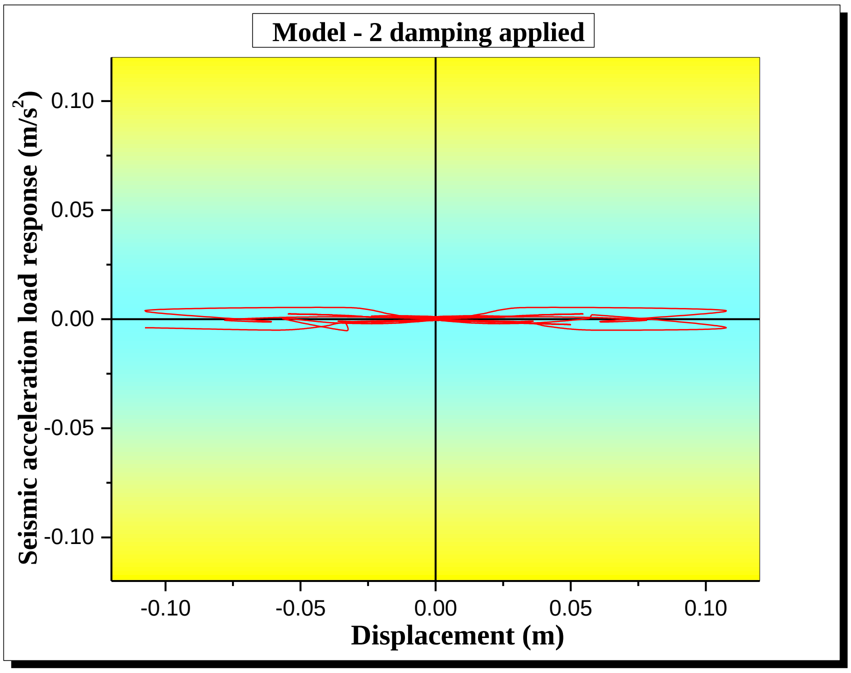


Figure 7. Seismic response-displacement of floor with applied calculated damping ratio

Figures 8 to 13 show column strain, column lateral displacement, and timber frame acceleration load response. In the comparison the seismic response of timber floor with timber column in view of seismic design, it has been found that the with realistic apply damping ratio in the numerical modeling the strain energy in the column has been reduced with appropriately distribution seismic load on the timber structure. The nonlinear strain energy exceeding seismic load input waves. While the elastic deformation in the column is very small compared to the floor. However, timber floor has large nonlinear elastic behavior with not considering the damping ratio, this nonlinear elastic timber behavior is a key point in timber structure seismic design. The major mode of plastic deformation in the numerical analysis shows the seismic stability of the timber frame, it is in the first mode, however the only six modes have been applied in calculation damping ratio.

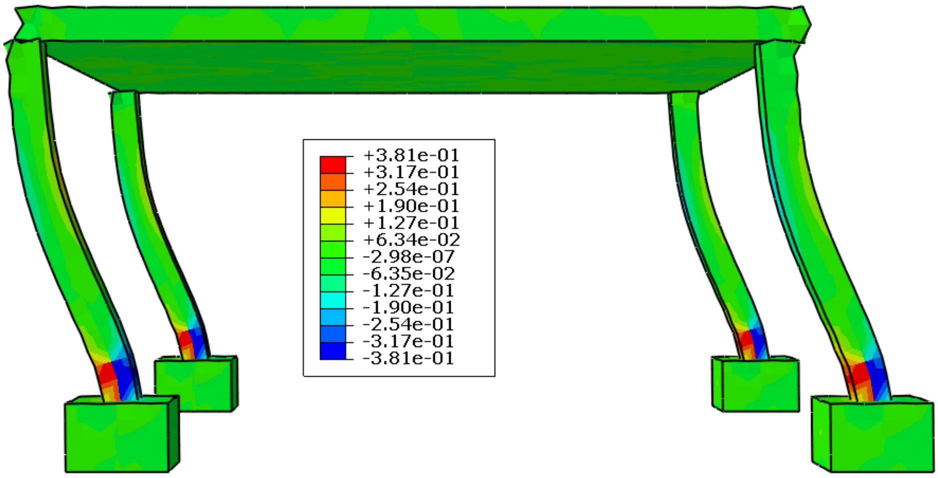


Figure 8. Column strain not applied damping ratio

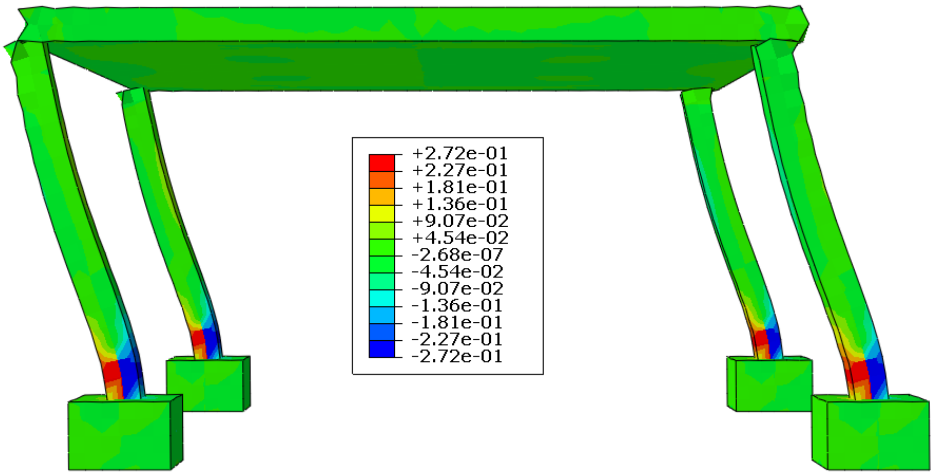


Figure 9. Column strain applied damping ratio

The energy transfer from the applied forcing frequency in respect to damping ratio was found to be highly desirable in simulate seismic loading. To enhance earthquake resistant a timber structure, realizing scattering and reflecting strain energy in associate to damping will technically and economically are required. The finite strain plasticity shows that the damping ratio reformed the strain energy dissipation mechanism through the timber structure, this phenomenon shows in Figures 4 to 13. The transferring seismic load arising during the damping ratio has not been calculated in an earthquake. The resist transfer forces has been illustrated in the timber frame seismic load response.

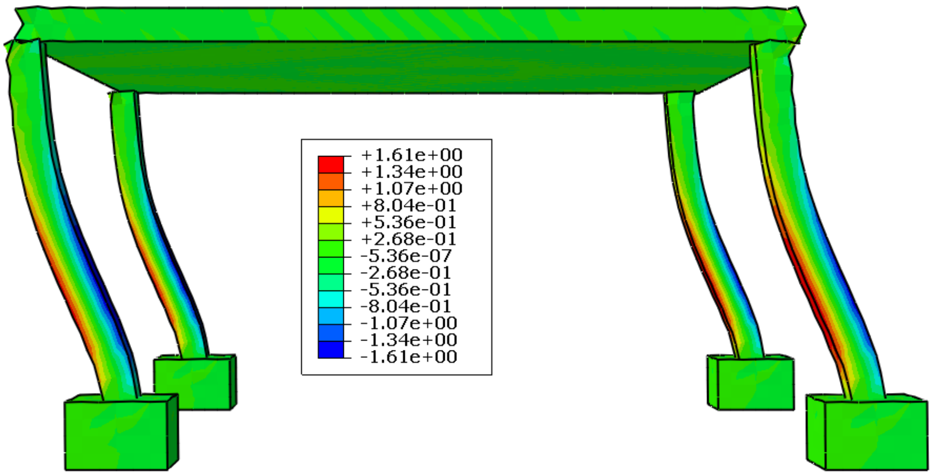


Figure 10. Column lateral displacement not applied damping ratio

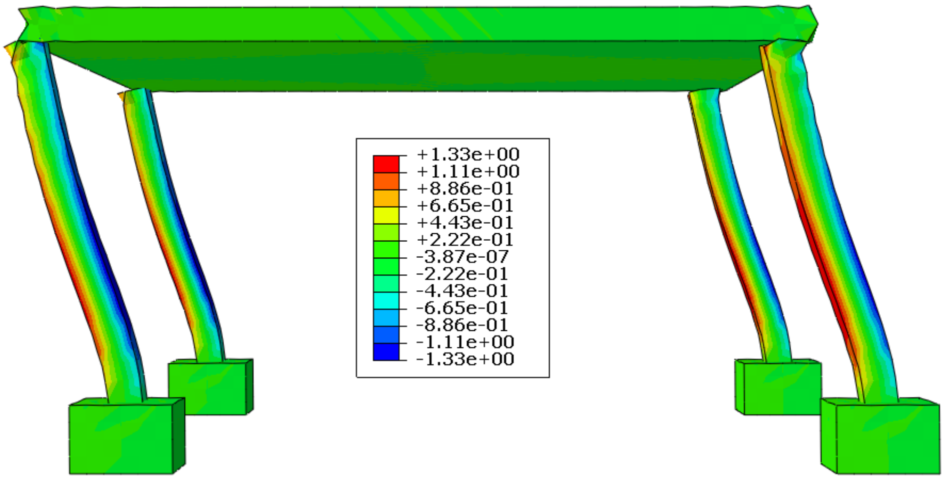


Figure 11. Column lateral displacement applied damping ratio

The damping ratio playing the significant role to estimate the strength of timber structural elements. The ground motions with strong acceleration time histories associated to displacement and damage of structural elements. On the other hand, the variation of structural elements deformation is accelerated damage due to converting elastic deformation to nonlinear plastic deformation. Figures 12 and 13, show two different seismic transfer loading in the column for the numerical analysis related to apply damping ratio in the model.

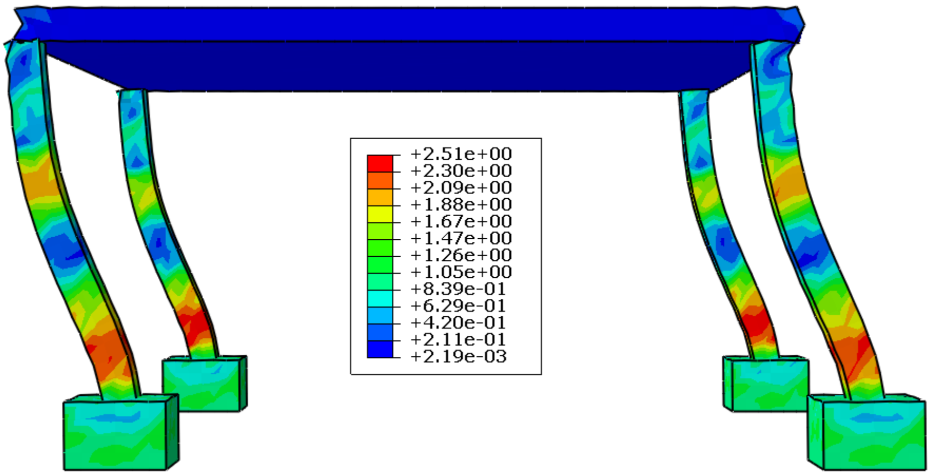


Figure 12. Timber frame acceleration load response not applied damping ratio

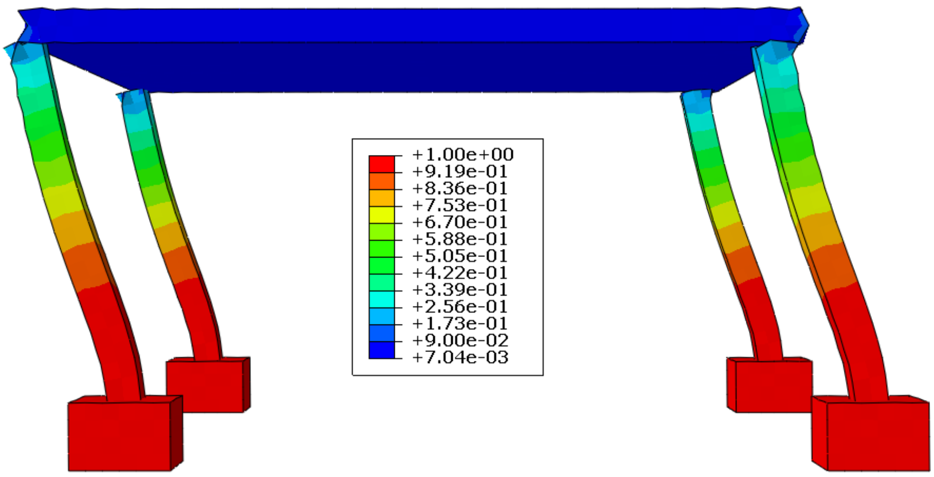


Figure 13. Timber frame acceleration load response applied damping ratio

Floor seismic load response was lower, and minimize the risk of damage observed in the floor and the cost-effective design policy for timber buildings are required for timber seismic design. The monitoring vibration by means finite element modeling of timber single structure shows that the potential damage and elastic deformation at floor and column is not the same. The larger displacement and damage to non-structural element is clearer with accurate numerical simulation.

4. Conclusion

The strain density, displacement and seismic load response of the timber floor and column were described. The suitable number of eigenvalues for calculate natural frequency and damping ratio when the model is subjected to forcing frequency examined. The damping ratio was calculated by means complex frequency method, and it applied in finite element method. The variation of damping ratio is the main concern in this study to analysis strain, displacement and load seismic response of the timber structure floor. It has been found that the floor of timber structure has more vertical displacement compared to column, but the nonlinear deformation of the floor has been reduced with moderation seismic load response. The nonlinear deformation of timber floor response has a direct relationship with the level of damping ratio. The numerical analysis results show that the inertial interaction and strain energy dissipation related to strain energy density and it vary in respect to damping ratio. In calculating the damping ratio, the complex frequency method gives suitable results. In the comparison the seismic response of timber floor with timber column in view of seismic design, it has been found that the with realistic apply damping ratio in the numerical modeling the strain energy and in the column have been reduced with appropriately distribution seismic load in the timber structure.

5. Conflicts of Interest

The authors declare no conflict of interest.

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