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A PRACTICAL ALGORITHM FOR MODELING OF FRICTION DAMPED-BASED STRUCTURES

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With the emergence of friction damper, it becomes economically feasible to significantly increase the earthquake resistance and damage control potential of a structure. Friction dampers are of the most efficient methods of dissipating seismic energy. In general, friction tools well perform against earthquake and their response is independent of loading range, frequency and number of loading cycles.

Damping through friction tends to be one of the most efficient methods of dissipating seismic energy. Therefore, dynamic modeling of friction dampers have found a significant aspect in the exploration of performance and reliability of them within structures. However, traditional methods are highly depending on the rectangular hysteretic loop in which the whole structure behavior is only modelled by spring-mass system. This paper deals with a practical algorithm to analyze the behavior of various bending, braced, and specifically friction–damped based structures.

The novelty of the presented algorithm is hysteresis-less essence that enables the multi-degree of freedom analysis of structures based on master and slave degrees of freedoms, dynamically through solving reduced order motion equation without the knowledge of mechanical hysteresis loop. Moreover, Numerical results show that the computational complexity of the presented method is one fifth of the traditional ones at higher story buildings.

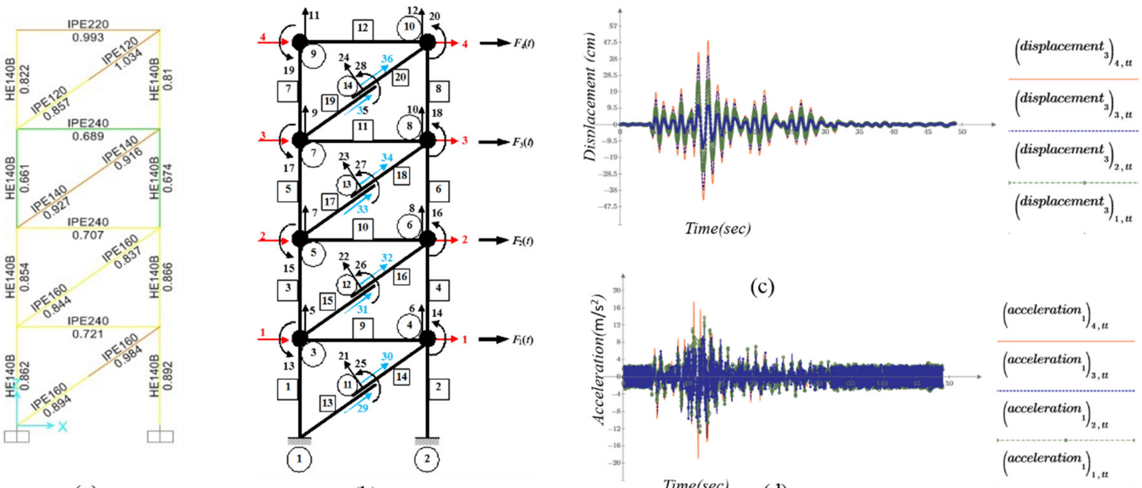
Based on static condensation, if a system is in a dynamic equilibrium, each member of the system would be in the same situation. However, in order to simplify the computational process and avoiding the non-singular matrices, some number of DOFs should be removed. Therefore, we can define two class of DOFs named master (e) and slave (i) as shows in Equation 1. It is noticeable that there is no dynamics loading on slave DOFs.

$$\begin{bmatrix} M_{ee} & O_{ei} \\ O_{ie} & O_{ii} \end{bmatrix} \begin{bmatrix} \ddot{x}_e \\ \ddot{x}_i \end{bmatrix} + \begin{bmatrix} K_{ee} & K_{ei} \\ K_{ie} & K_{ii} \end{bmatrix} \begin{bmatrix} x_e \\ x_i \end{bmatrix} = \begin{bmatrix} F_e \\ F_i \end{bmatrix} \quad (1)$$

In the condensed motion equation, the force vector of master DOFs means $\{F_e\}$, is the same vector of external forces (i.e., earthquakes). In the same way, the vector of forces related to slave DOFs are the vector in which frictional forces $\{F_i\}$ are placed. Doing some mathematical computations, $f_{nl}(\dot{x})$ would be resulted which is the vector of nonlinear forces due to the friction damper. Finally, Coulomb friction force has been obtained as Equation 2 based on friction coefficient (μ), normal force of slip load (S_i), and $sgn()$ which is a signal function. Also, $\dot{x}_i$ shows the velocity vector between ends of the friction damper.

$$f_{nl}(\{\dot{x}_i\}) = -\{\mu S_i\} sgn(\{\dot{x}_i\}) \quad (2)$$

In fact, the main concern of the presented paper is that instead of solving the set of (*N*-1) linear equations, they can be reduced to a single non-linear equation whose only unknown is the amplitude of motion of the structure DOF attached to the friction damper. Then, the motion equation was excited by earthquake records at time *t.* The problem has been solved using the Newmark algorithm to find the acceleration and displacement of each instance. As a prototype, we investigate four-story damped building in which one friction damper with four degrees of freedom is used in each floor. The analyzed structure under porposed algorithm is shown in Figure 1.



(a) (b) (d)

Figure 1. (a) Schematic of four story damped-frame structure (b) Analyzed friction-damped frame under proposed algorithm (c) displacement response per story (d) acceleration response per story.

The concluded results has been addressed in Table 1. It is noticeable that top acceleration and displacement of structures with friction damper can be controlled effectively.

Table 1. Numerical results of structures under various earthquakes.

No.	Type of Structure		Earthquake	Top acceleration (m/s^2)			Top displacement (cm)		
				Bending	**Braced**	**Friction**	**Bending**	**Braced**	**Friction**
1	1-Bay	4	El-Centro	14.49	27.14	5.34	30.3	5.8	7.7
2		6		11.59	44.62	6.01	36.5	20.2	12
3		10		21.33	18.64	5.76	54.3	30.3	46
4		4	Manjil	14.05	53.25	4.51	30.2	12.7	7.40
5		6		13.16	22.63	4.39	35.24	12.6	33.12
6		10		11.62	21.6	3.84	24.60	12.6	30.5
7	2-Bay	4	El-Centro	10.79	26.83	5.81	24	8.4	5.7
8		6		17.81	27.34	5.78	39.7	19.2	15.5
9		10		16.63	23.53	5.47	51.8	34.7	33.60
10		4	Manjil	8.43	35.60	4.37	21.7	10.8	4.7
11		6		16.64	31.4	4.37	31.6	18.5	9
12		10		8.90	38.08	5.06	18.4	14.4	28.9

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