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Probability Distribution of ADAS Metal Dampers in R.C. Buildings Using Nonlinear Analysis

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Abstract: This study discusses the effect of metallic yielding dampers (ADAS) on the behavior of reinforcement concrete buildings when exposed to seismic shocks. The objective of the study is to reduce the negative impacts on the main structural elements (plastic, fall) by using the technique of metallic dampers. The method of metallic dampers is one of the modern ways based on the principle of dissipating the resulting energy from the seismic shock and reducing the needed energy in the main structural elements of the building to keep it in a flexible state. This technique also provides a controlling mechanism for story displacement, the handling of the soft story mechanic and the torsion mechanic of the buildings.

In this study, the effect of the addition of ADAS dampers on the construction behavior was observed in terms of (building period, base shear, roof displacement, roof acceleration, story displacement, dissipative energy). Based on the preceding, this study will give the possibility of predicting the behavior of the building when using ADAS metal dampers in the reinforced concrete structures with their distribution methods.

Keywords: Added damping and added stiffness, ADAS damper, Energy dissipate.

التوزيع الاحتمالي لمخمدات معدنية من نوع ADAS في المباني البيتونية المسلحة باستخدام التحليل اللاخطي

هاله توفيق حسن

المعهد العالي للبحوث والدراسات الزلزالية || جامعة دمشق || سورية

خالد الحمصي

المستخلص: تناقش هذه الدراسة تأثير المخمدات المعدنية (ADAS) على سلوك المباني الخرسانية عند تعرضها للهزات الزلزالية، كان الهدف من الدراسة هو تخفيض الضرر على العناصر الانشائية الرئيسية (المفاصل اللدنة، الانهيار) باستخدام تقنية المخمدات المعدنية ADAS، و تعتبر هذه الطريقة من الطرق الحديثة القائمة على مبدأ تبديد الطاقة الناتجة من الهزة الزلزالية وتبديد الطاقة اللازمة في العناصر الانشائية الرئيسية للمبنى لإبقائه في الحالة المرنة، وتوفر هذه التقنية آلية التحكم في ازاحة الطابق والتعامل مع ميكانيكية الطابق اللين وميكانيكية الفتل.

لوحظ في هذه الدراسة تأثير إضافة مخمدات ADAS على سلوك المبنى من حيث (دور البناء، القص القاعدي، إزاحة الطوابق، تسارع الطابق، الطاقة المبددة).

وكانت حالة وضع مجموعات التخميد في خط عمودي في وسط الواجهات في كلا الاتجاهين أدى النموذج إلى أفضل النتائج لحالة تقليل فترة البناء بنسبة 8.95% وتقليل إزاحة السقف بنسبة 24.54% وتقليل إزاحة القصة بنسبة 35% وتبديد أكبر طاقة والتي بلغت 22.44%.

وبناء على ما سبق، أعطت هذه الدراسة إمكانية التنبؤ بسلوك المبنى عند استخدام مخمدات ADAS المعدنية في المباني الخرسانية المسلحة مع طريقة توزيعها.

الكلمات المفتاحية: رفع كفاءة المباني الخرسانية المسلحة، إضافة مخمد، إضافة قساوة، مخمد ADAS، تبديد الطاقة.

1- Introduction.

The design theory of seismic resistance depends on the resistance of seismic side loads due to the stiffness and resistance of structural elements caused by the weak and medium earthquakes, reliance is placed on the lateral displacement control, avoiding the collapse of structural elements through the ductility of components and the dissipation of energy caused by strong earthquake.

The core approach to energy dissipation in construction is to allow for local damage to structural elements (i.e. plastic joints) in the basic elements that are resistant to side loads. These elements require replacement or repair after the earthquake occurs to restore its side strength, stiffness and energy dissipation capacity.

Several theories have been developed to evolve some innovative techniques to improve the performance of elements exposed to an earthquake by minimizing damage to side-loading components. These techniques include adding additional devices to the structural structure to absorb and dissipate the energy of the seismic shock. The ADAS (Added damping and added stiffness) in all its forms is the focus of this research.

2- Research objective:

The objective of this study is to study the effect of the probability distribution of ADAS damping devices in reinforced concrete buildings under the influence of the analysis of time history on the building's response to seismic shock (building period, base shear, roof displacement, roof acceleration, story displacement, dissipative energy). Achieve this objective is through following the steps below:

- Study the effect of the probability distribution of ADAS in five cases.
- Parametric study: impact on the response of the construction of seismic shock (building period, base shear, roof displacement, roof acceleration, story displacement, dissipative energy).

3- Research Methodology:

1. A summary of the ADAS dampers and its features.
2. Review previous research.
3. Analytical study using the ETABS program:
   - Modeling of a 14-stories concrete frame building, with the same specifications of the reference study as Keykhosravi & Aghayari (2017). its structural that is resistant to seismic loads.
   - Calibration.

- The probability distribution of the damping groups according to the engineering parameters of the dampers used in (Narkash, 2017) according the following models:
  M1: The damping groups shall be placed in a vertical line at the center of the facades in both directions, M2: The damping groups shall be placed in vertical line with the sides of the facades in both directions, M3: The damping groups shall be placed in a horizontal line on the upper floors of the building in both directions, M4: The damping groups shall be placed in a horizontal line with the middle floors of the building in both directions, M5: The damping groups shall be placed in a horizontal line on the lower floors of the building in both directions.

4. Conclusions of the effect of the distribution of the dampers in the previous cases and to determine the best cases for this response.

4- Literature (theoretical content of ADAS):

4-1 Definition of ADAS Dampers:

The ADAS is a compilation of metal plates with triangular or X-shaped cross-sections placed parallel to each other in these devices, and attached to the frames in the building connected to the bottom of the beam center with a plate (top), and connected to the top of the bracing with a plate (bottom) from the other side as shown in Fig. (1). So that the displacement of the floor move the upper part of the device is damped horizontally for the bottom, allowing the hysterical power to be dissipated by yield bending in the sheet metal according to Sahoo, Singhal, Taraithia, & Saini (2015).

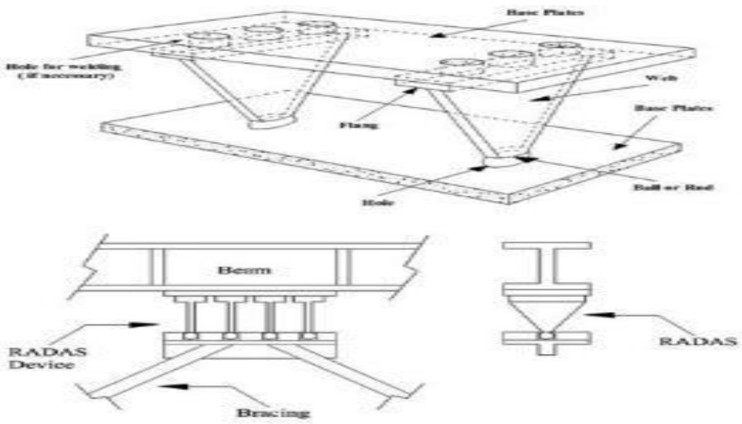


Fig. (1) ADAS Dampers as Sahoo, Singhal, Taraithia, & Saini (2015).

4-2 Distribution of horizontal forces in ADAS dampers:

The forces resulting from the seismic impact on the building include mainly shear forces in column (F_C) and horizontal forces in the dampers (F_R), ADAS devices are designed to absorb seismic forces to keep the force of the column less than the designed forces of the column at any time of the seismic shock. (F_T) is the maximum shear forces of the frame, without the ADAS devices on each floor during the earthquake, (F_D) is the design shear forces of the columns and (F_R) is the resistive forces in the ADAS dampers that we design, if ($F_T > F_D$), the objective of using ADAS dampers is to absorb the difference between (F_T - F_D), So that does not exceed (F_C) during the earthquake, as shown in Fig. (2), according to (Abdollahzadeh & Bayat, 2010), and from which we find Eq. (1).

$$F_R = F_T - F_D \tag{1}$$

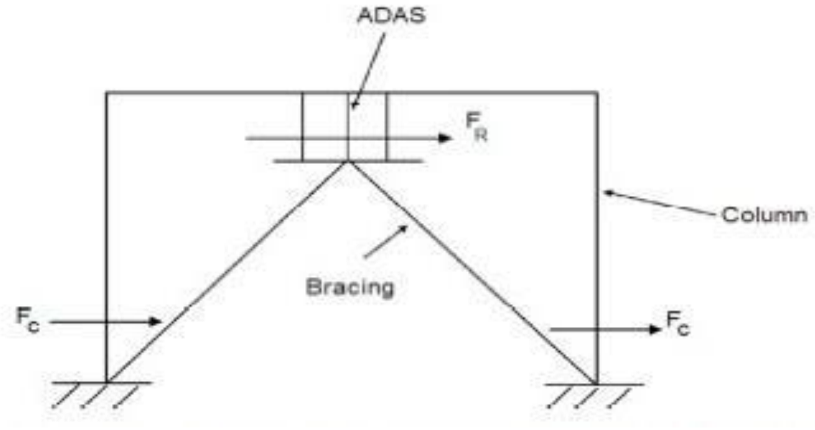


Fig. (2) Distribution of Shear Forces during Seismic Shock (Abdollahzadeh & Bayat, 2010).

5- Reference Study:

The building of a reinforced concrete frame has been modelled, as the structural is resistant to earthquakes are circumferential frames in both directions to be earthquake-resistant and then added the metal bracing in the form of V inverted, according to (Keykhosravi & Aghayari, 2017). as shown in figure (5) the plan was 5 consecutive span with a (5 m) distance and (3 m) height, which is consisting of 14 stories as shown in Fig. (3).

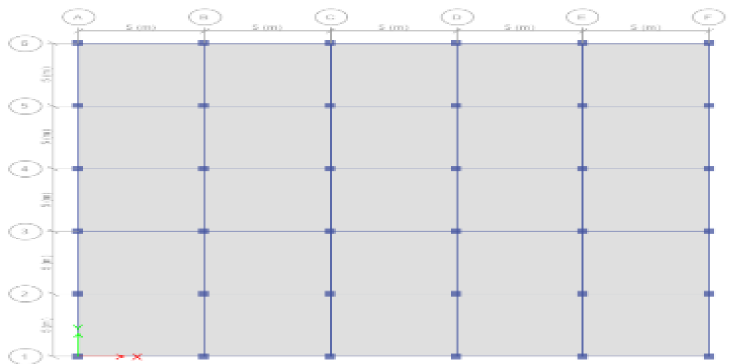


Figure (3) Typical Plan as Keykhosravi & Aghayari (2017).

The studied structures were designed according to UBC97 code, dead loads $4\ kN/m^2$ and live loads $2\ kN/m^2$ were considered.

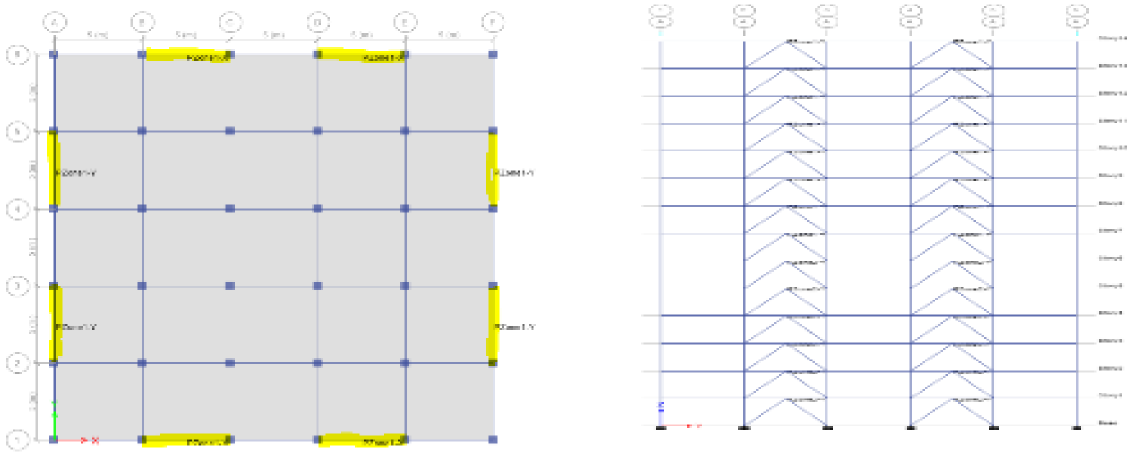
6- Analytical Study:

6-1 Work phases:

- In the first phase (prototype) circumferential frames in both directions to be earthquake-resistant systems, and the results were calibrated with the previous study (Keykhosravi & Aghayari , 2017).
- In the second phase, the probability distribution of the damping groups was performed in different cases (5 cases), and the results of the building response to these cases were determined and the best cases were identified.

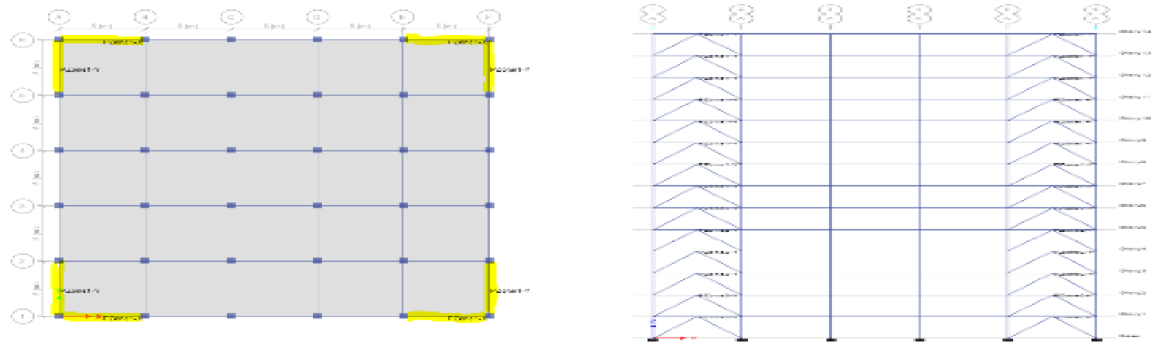
  These cases are:

  - M1: The damping groups shall be placed in a vertical line at the center of the facades in both directions as shown in Fig (4).
  - M2: The damping groups shall be placed in vertical line with the sides of the facades in both directions as shown in Fig (5).
  - M3: The damping groups shall be placed in a horizontal line on the upper floors of the building in both directions as shown in Fig (6).
  - M4: The damping groups shall be placed in a horizontal line with the middle floors of the building in both directions as shown in Fig (7).
  - M5: The damping groups shall be placed in a horizontal line on the lower floors of the building in both directions as shown in Fig (8).



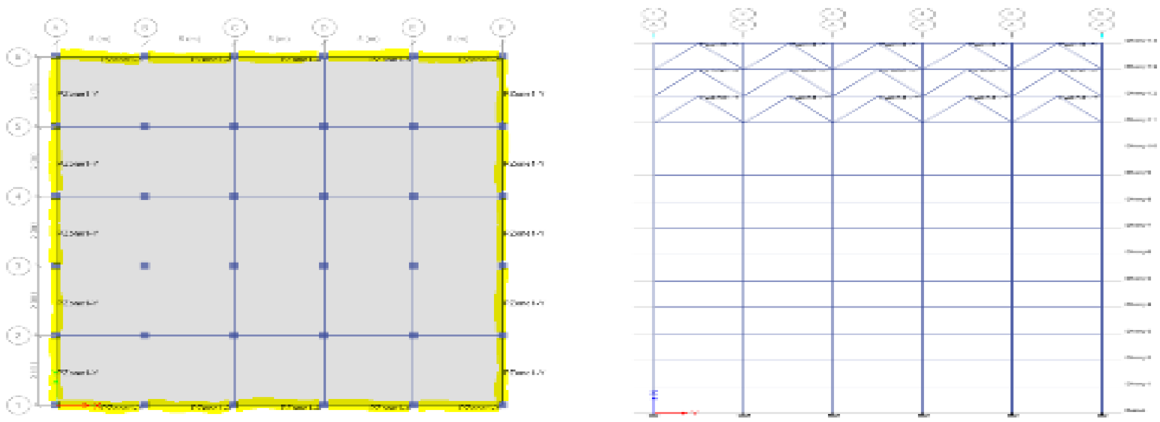
(a) Model Plan **(b) Model Section**

Fig. (4) Model M1



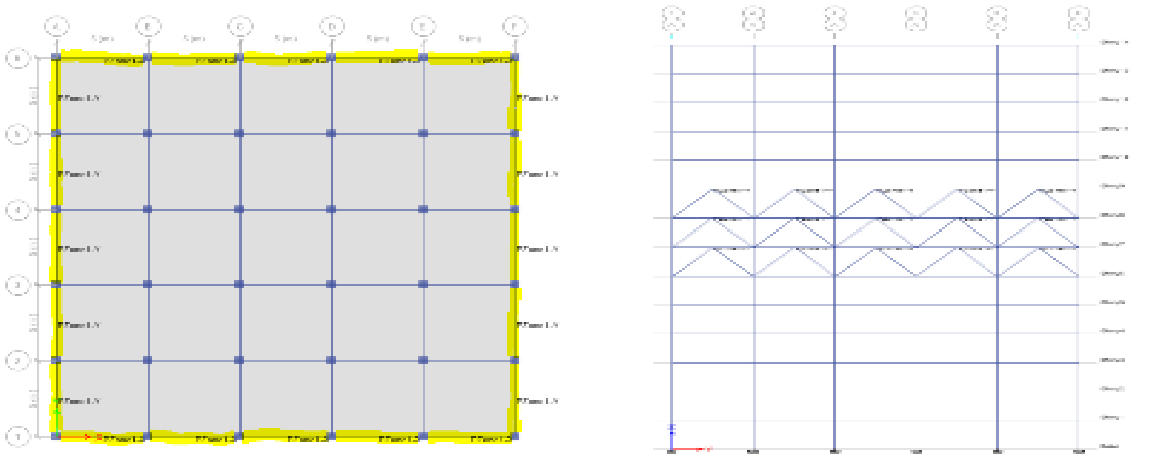
(a) Model Plan (b) Model Section

Fig. (5) Model M2



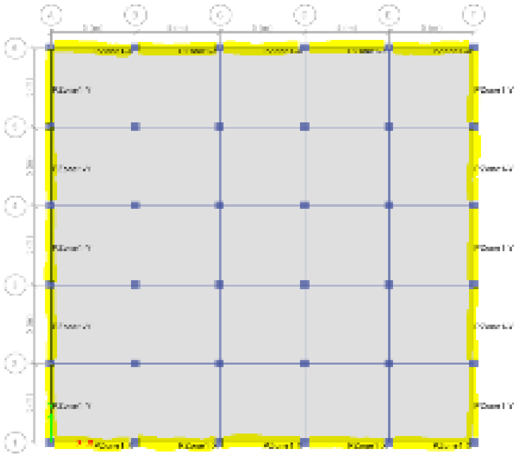
(a) Model Plan (b) Model Section

Fig. (6) Model M3

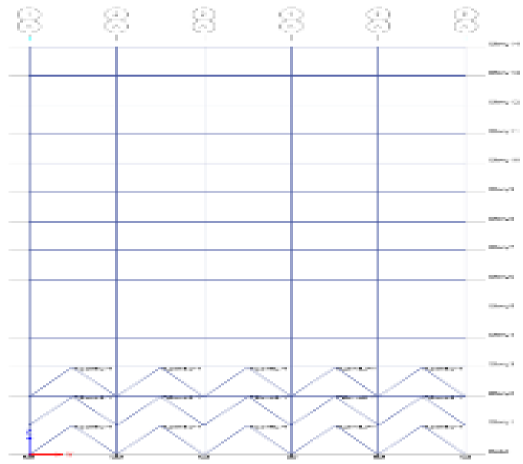


(a) Model Plan (b) Model Section

Fig. (7) Model M4



(a) Model Plan



(b) Model Section

Fig. (8) Model M5

6-2 Properties of materials and sections used:

Table (1) properties of materials used (Keykhosravi & Aghayari, 2017).

	Rebar	Braces	Concrete
$F_Y\ (MPa)$	400	355	-
$E\ \ (GPa)$	200	200	26.5
ν Poisson's	0.30	0.30	0.20
$f'_c\ (MPa)$	-	-	30

Table (2) Sections used (Keykhosravi & Aghayari, 2017).

Section (Unit)	Story
Column 50*50	13-14
Column 60*60	10-11-12
Column 70*70	5-6-7-8-9
Column 80*80	1-2-3-4
Beam 40*40	13-14
Beam 45*45	10-11-12
Beam 50*50	5-6-7-8-9
Beam 60*60	1-2-3-4
Braces 2UNP 100*10	1 to 6
Braces 2UNP 80*8	7 to 14

6-3 Specification of damping groups:

The damping group is the bracing with addition to the ADAS, and the damper is the type of passive control dampers $F_Y\ 240(MPa)$, the elasticity factor (E = 200,000 MPa), the shape and dimensions of the dielectric plate, (T = 8 mm), width (B = 160 mm) and height (H = 170 mm), according to (Narkash, 2017), as shown in Fig. (9).

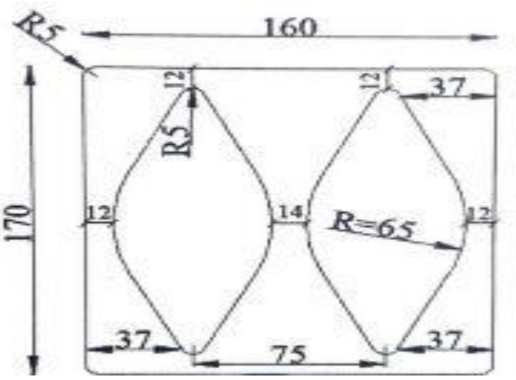
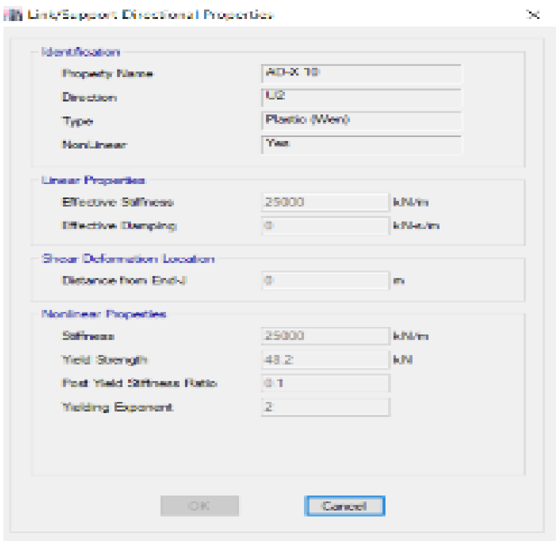
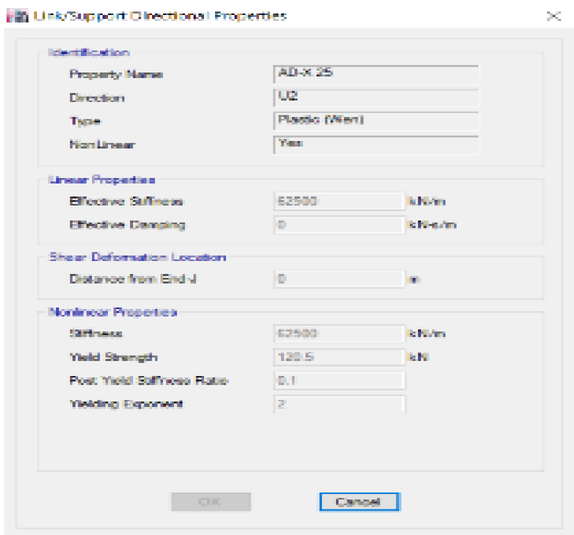


Fig. (9) Dimension of the Plate as Narkash, (2017).

Two different types of dampers were used in the number of plates (10 and 25) (Braces 2UNP 80 * 8, Braces 2UNP 100 * 10) on the sequence. The most critical variables for the damping system are (SR, B / D, N, PGA) these are the sequence (ratio of the stiffness of damping group to the stiffness of the frame, ratio of the stiffness of the damping to the stiffness of the bracing, the number of plates in the damper, the intensity of the seismic acceleration).

These dampers are defined within the ETABS 2016 environment, as links with their engineering specifications of stiffness and strength of yield, as shown in Fig. (10), according (Narkash, 2017).



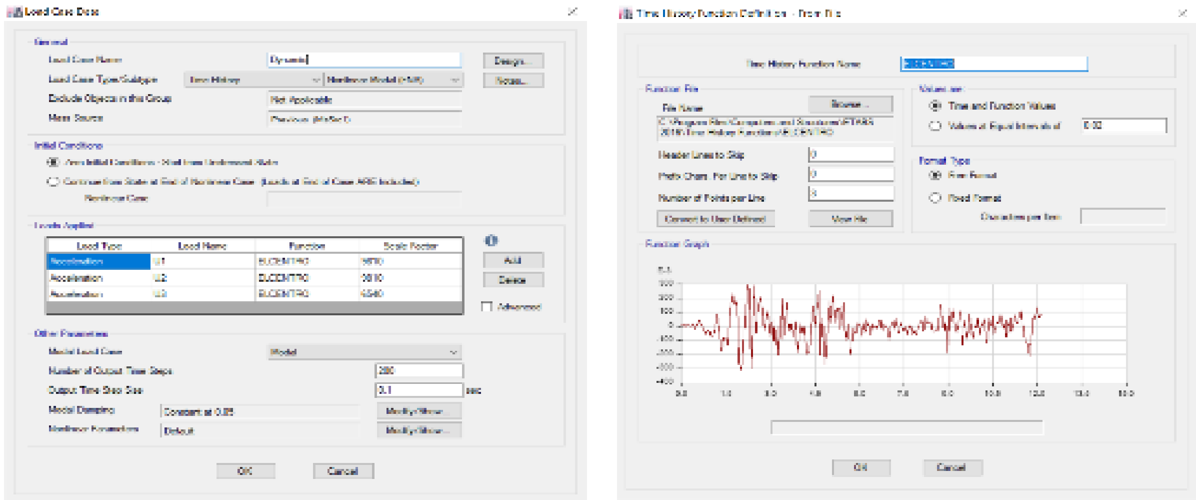


(a) 10 Plates **(b) 25 Plates**

Fig. (10) Definition Damper

6-4 Curve Loading We use:

ELCentro seismic time history log has been used, Fast Nonlinear Analysis (FNA), with a maximum acceleration of 0.32 g, the duration of the quake is 20 sec, as shown in Fig. (11).



(a) Application ELCentro **(b) Curved loading ELCentro**

Fig. (11) Definition Curve ELCentro

7- Results:

7-1 Analytical results:

The Table 3 shows the results of the reference study, according (Keykhosravi & Aghayari ,,2017):

Table (3) The Results of the Reference Study

Model	Te (sec)
Frame	1.84
Bracing	1.49

The following Table 4 shows the results of the frame model study and the results of adding the bracing only to be calibrated with the previous study. The table shows the results (building period, base shear, roof displacement, roof acceleration).

Table (4) The Results of the Frame Model Study

Model	T (sec)	V (kN)	U (mm)	A (m/sec^2)
Frame	751.	18692.6	261.5	6.72
Bracing	1.46	17867.4	216.3	6.64

The following Table 5 shows the results of the study of probability distribution models for damping groups. The table shows the results (building period, base shear, roof displacement, roof acceleration).

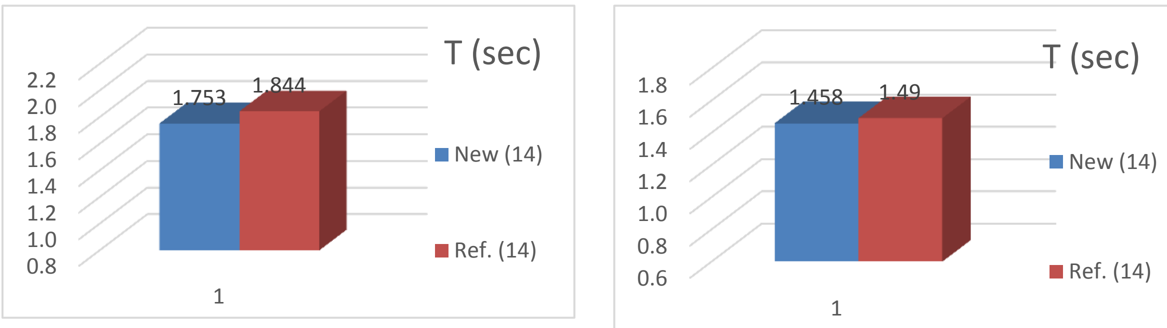
Table (5) The Results of the Study of Probability Distribution

Model	T (sec)	V (kN)	U (mm)	A (m/sec^2)
M1	1.60	17378.2	197.3	6.72
M2	1.61	17210.4	206.0	5.61
M3	1.73	17955.2	256.8	7.15
M4	1.67	17761.6	231.4	6.83
M5	1.71	17863.0	242.6	5.25

7-2 Calibrate the period of the building (Phase 1):

It is clear to us in the following Chart that the ratio of the difference in the building period in the case of the frame model between the reference study and the re-study in the first phase did not exceed 5%, as shown in Fig. (12-a).

In the following Chart, we find that the ratio of the difference in the building period in the case of the frame model with bracing between the reference study and the re-study in the first phase did not exceed 2.5%, as shown in Fig. (12-b).

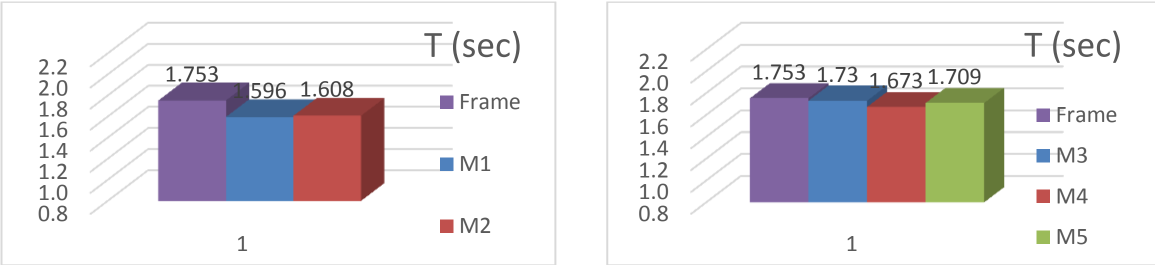


(a) Frame Model **(b) Bracing Model**

Fig. (12) Period of the Building (Phase 1)

7-3 Comparison of the building period (probability distribution):

In the following Charts, we can clearly see the decreasing in the period of the building in a different ratio between the models of probability distribution than the case of the frame model before the addition of dampers is shown in the following Charts: 8.95% in M1 and 8.27% in M2 and 1.31% in M3 and 4.56% In M4 and 2.651% in the M5 model, from which we found that the M1 and M4 distribution status was the case that showed to the highest rates of reduction in the building period, as shown in Fig. (13).

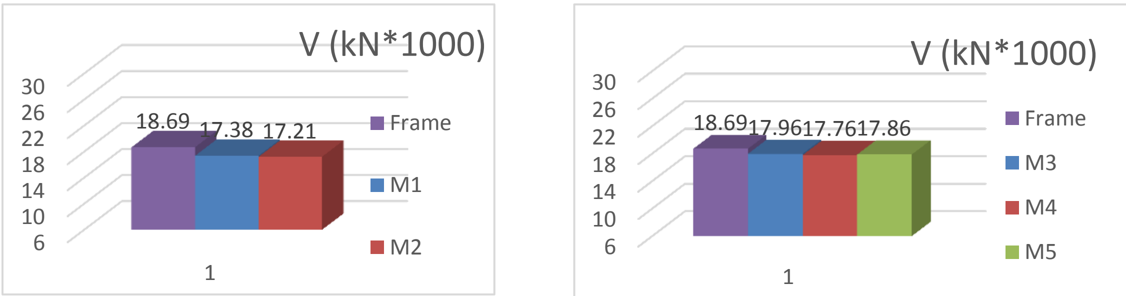


(a) Model (M1, M2) **(b) Model (M3, M4, M5)**

Fig. (13) Period of the Building (probability distribution)

7-4 Comparison of the base shear (probability distribution):

In the following charts we can see the reduction of the base shear in different ratio between the probability distribution models from the case of the frame model before the addition of the dampers. The reduction was 7.01% in the M1 model, 7.92% in the M2 model, 3.91% in the M3 model and 4.98% In M4 and 4.44% in the M5 model, from which we found that the state of the M2 and M4 distribution was the case that showed to the highest rates of reduction in the base shear, as shown in Fig. (14).

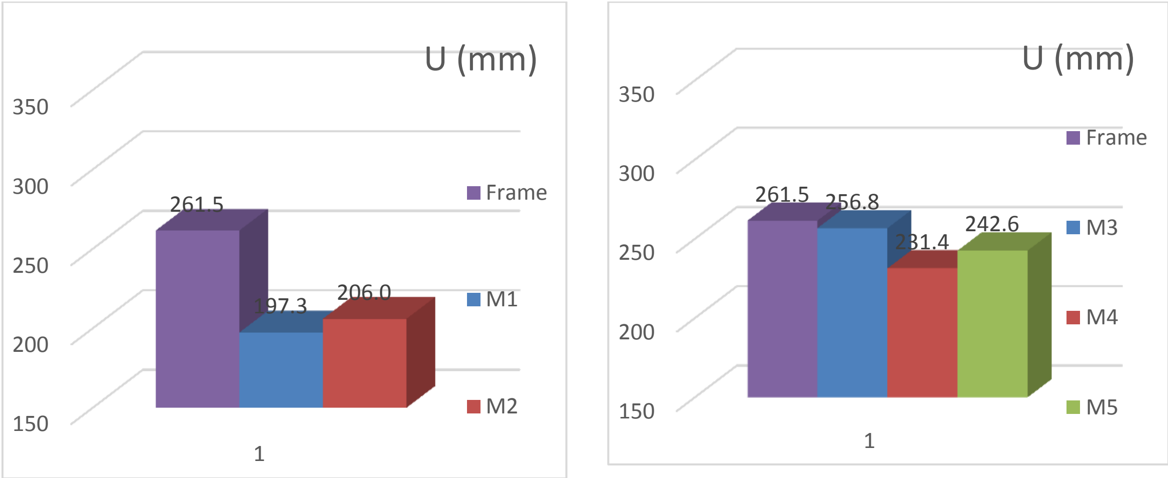


(a) Model (M1, M2) **(b) Model (M3, M4, M5)**

Fig. (14) Base Shear (probability distribution)

7-5 Comparison of the roof displacement (probability distribution):

In the following charts we can see the reduction of the roof displacement in different ratio between the probability distribution models from the case of the frame model before the addition of dampers. The reduction was 24.54% in the M1 and 21.22% in the M2 and 1.80% in the M3 and 11.50 In M4 and 7.22% in the M5 model, from which we found that the M1 and M4 distribution status was the case that showed to the highest rates of reduction in the roof displacement, as shown in Fig. (15).

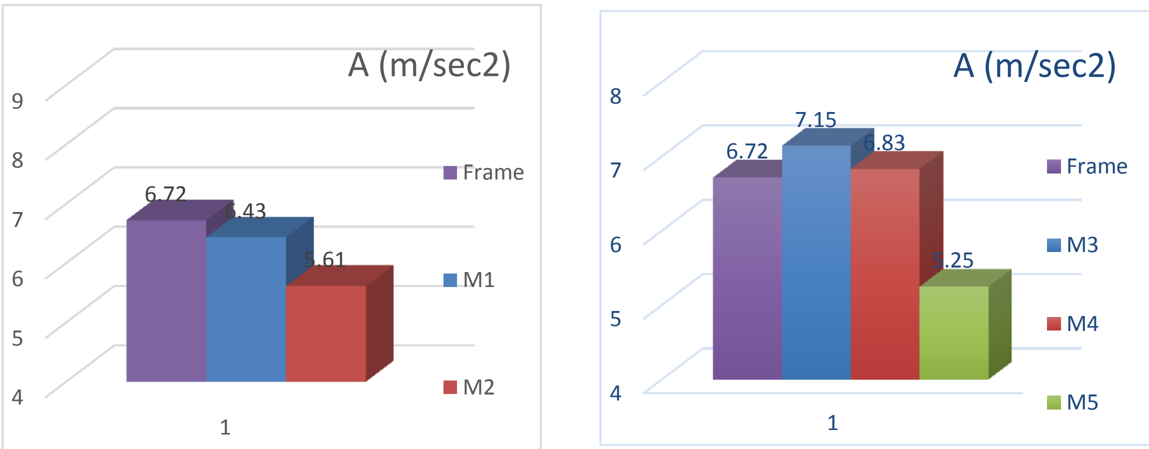


(a) Model (M1, M2) (b) Model (M3, M4, M5)

Fig. (15) Roof Displacement (probability distribution)

7-6 Comparison of the roof acceleration (probability distribution):

In the following charts we can see the reduction of the roof acceleration in different ratio between the probability distribution models from the case of the frame model before adding the dampers. The reduction was 4.32% in the M1 model, 16.52% in the M2 model and 6.40% in the M3 and 1.64 % In M4 and 21.88% in the M5 model, from which we found that the M2 and M5 distribution status was the case that showed to the highest rates of reduction in the roof acceleration, as shown in Fig. (16).



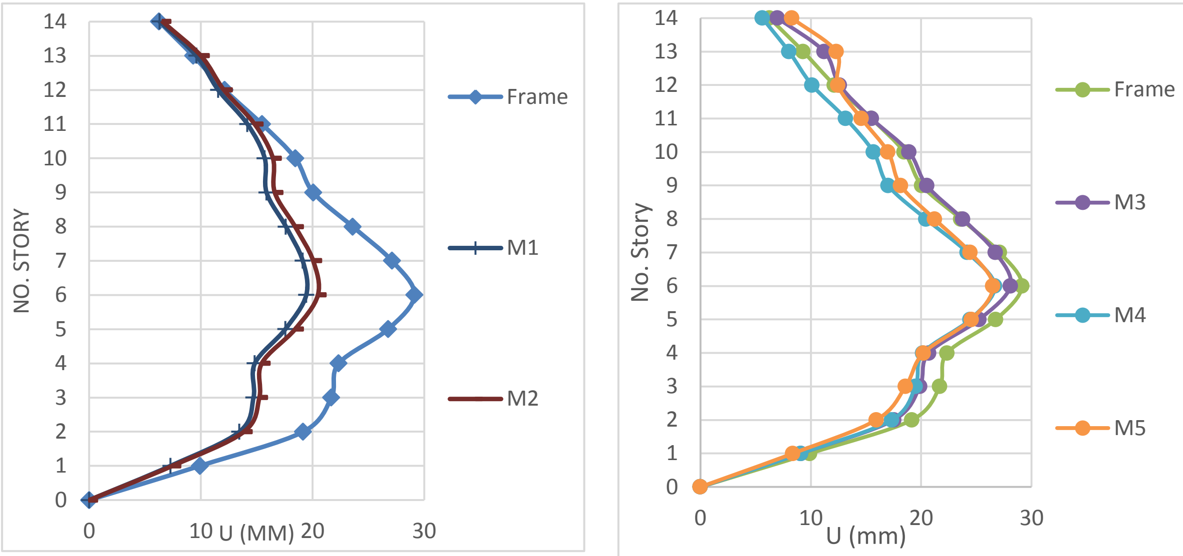
(a) Model (M1, M2) (b) Model (M3, M4, M5)

Fig. (16) Roof Acceleration (probability distribution)

7-7 Comparison of the story displacement (probability distribution):

In the following charts we can see the reduction of the story displacement in different ratio between the models of probability distribution than the case of the frame model before the addition of dampers, the reduction was 35% in M1 and 30% in M2 and 8% in M3 and 10% in M4 and 16% Model

M5, from which we found that the M1 and M5 distribution status was the case that showed to the highest rates of reduction in the story displacement, as shown in Fig. (17).

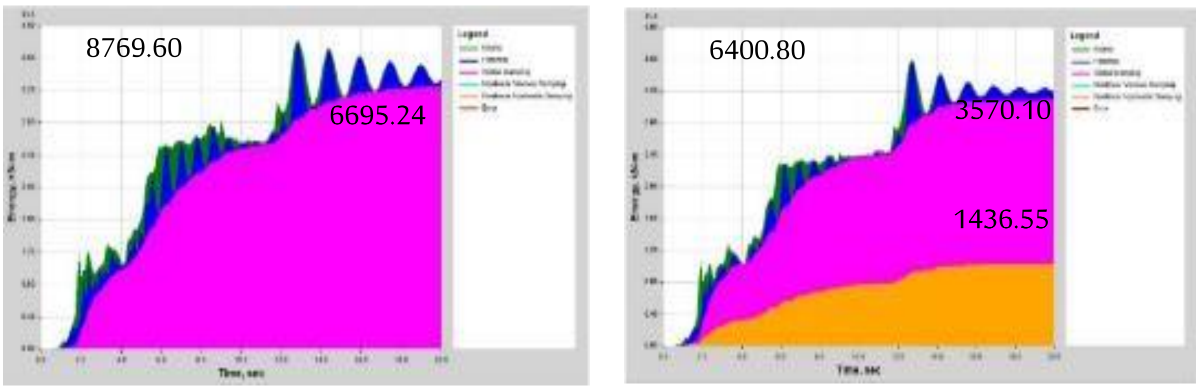


(a) Model (M1, M2) **(b) Model (M3, M4, M5)**

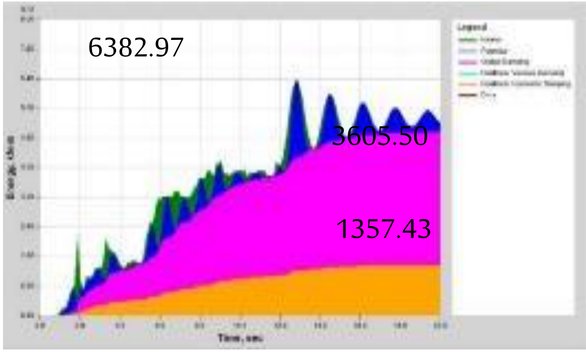
Fig. (17) Story Displacement (probability distribution)

7-8 Comparison of the dissipative energy (probability distribution):

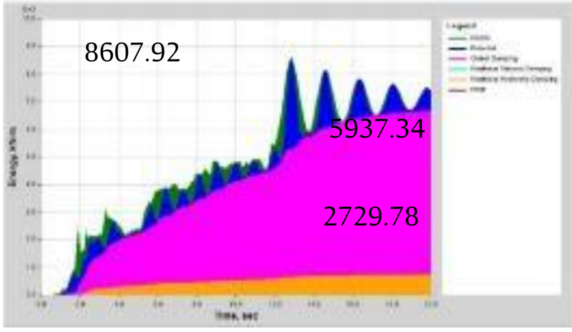
In the following charts we can see the reduction of the ratio of energy dissipation of the basic structural elements in different ratio between the models of probability distribution than the case of the frame model before the addition of dampers, so that the damping groups dissipated energy within and reduced them from the basic structural elements. The energy dissipation rates in the damping groups reached 22.44% in the M1 model, 21.27% in the M2 model, 8.53% in the M3 model, 8.96% in the M4 model and 9.90% in the M5 model, from which we found that the M1 and M5 distribution status was the case that showed to the highest energy dissipation rates in the damping devices, as shown in Fig. (18).



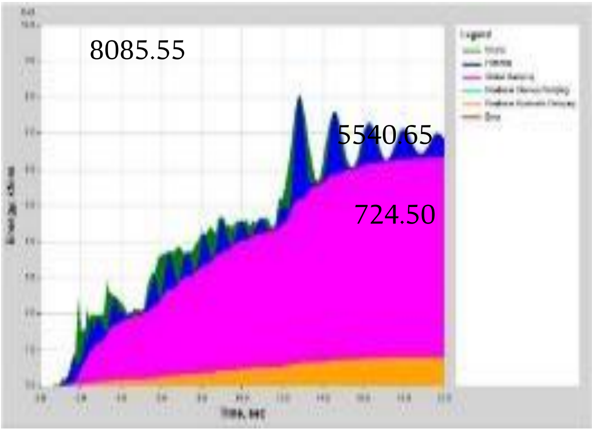
(a) Frame Model **(b) Model (M1)**



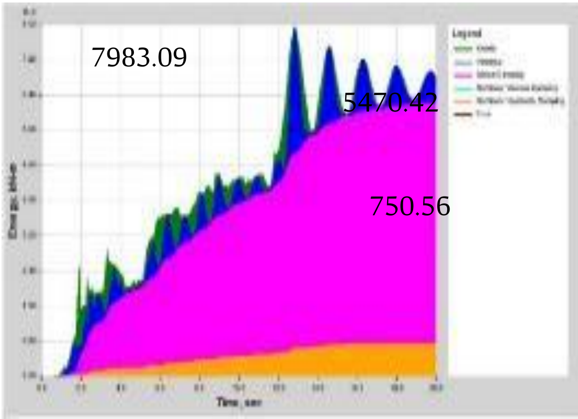
(c) Model (M2)



(d) Model (M3)



(e) Model (M4)



(f) Model (M5)

Fig. (18) Energy Dissipative (probability distribution)

8- Conclusion:

In this paper, the effect of adding the damping groups in the reinforced concrete frame buildings has a positive effect, It reduce the building period, the base shear, the roof displacement, the roof acceleration (acceleration control, especially on the upper floors), the story displacement (story displacement control) and keep the integrity of the basic structural (frame) by dissipating the energy generated by the seismic shock within the damping devices by reviewing the effect of the probability distribution of the damping groups according to five previously defined models and selecting the optimal distribution y influencing the building's response when exposed to seismic shock.

A case study of the probability distribution of damping groups on the reinforced concrete frame structures showed that:

1- The distribution according to the M1 model led to the best results of the case of reducing the building period by 8.95% and reduce the roof displacement by 24.54% and reduce the story displacement by 35% and the dissipation of the largest energy, which amounted to 22.44%.
2- The distribution according to the M2 model led to the best results of the case of reducing the base shear by 7.92% and reduce the roof acceleration by 16.52%.

3- The distribution according to the M3 model led to the results of the case of reducing the base shear by 3.91%.

4- The distribution according to the M4 model led to the best results of the case of reducing the building period by 4.56%, the reduction of the base shear by 4.98% and the reduction of the roof displacement by 11.5%.

5- The distribution according to the M5 model led to the best results of the case of reducing the roof acceleration by 21.88% and the reduction of story displacement by 16% and the dissipation of energy increased by up to 9.40%.

The best-case study of the probability distribution is intersection of cases M1 and (M4+M5)

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