Impact of Energy Dampers in Improvement of Impulsive Response of Double Layer Grids Space Structures

H. Zarrintala*
Department of civil engineering, Bonab Branch,
Islamic Azad University, Bonab, Iran
E-mail: h.zartala@hotmail.com
*Corresponding author

A. Maleki
Department of Civil Engineering, Maragheh Branch,
Islamic Azad University, Maragheh, Iran
E-mail: maleki_civil@yahoo.com

M. Darvishhashemi
Department of civil engineering, Bonab Branch,
Islamic Azad University, Bonab, Iran
E-mail: m_d_hashemi@yahoo.com

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Abstract: The main purpose of the study is to evaluate the effectiveness of these dead-points mono laterally in controlling the space location of the structures against the explosion loading in this regard. For the reason, nonlinear dynamical analyses on three kinds of structures under two layers' space location with two dead-points of FLD (Force Limiting Device) and TID (Tube Inversion Device) and without dead-point for explosion loading have been carried out and the related results were compared together in this case. For the related analysis, ABAQUS/Explicit software has been applied efficiently. This study shows that the destructor of inversed energy of the TID has an influential impact on the reduction of the displacement in this case.

Keywords: Double layer grids (DLGS), Energy dampers, Force limiting device, Tube inversion device

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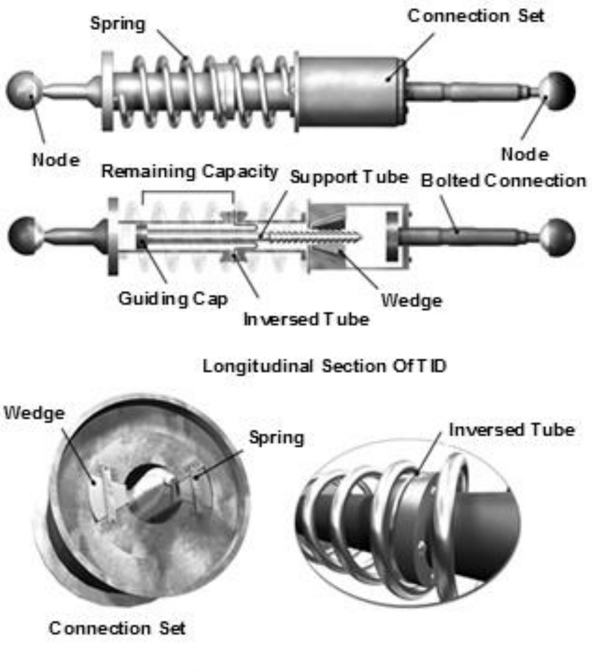
Biographical notes: H. Zarrintala received his MSc in Civil Engineering from Islamic Azad University of Maragheh in 2008. He is currently an Instructor at the Department of Civil Engineering, Islamic Azad University, Bonb, Iran. Currently he is PhD student in Islamic Azad University, Maragheh, Iran. His current research interest includes Concrete Technology and Space Structures. **A. Maleki** received his PhD from Kingstone University, England. He is the head of civil engineering department and managing director of professional engineering journal of Maragheh Azad University. **M. Darvishhashemi** received his MSc in Civil Engineering from Islamic Azad University of Maragheh in 2008. He is currently an Instructor at the Department of Civil Engineering, Islamic Azad University, Bonb, Iran. At present he is PhD student in Islamic Azad University, Maragheh, Iran. His current research interest includes Concrete Technology and Space Structures.

1 INTRODUCTION

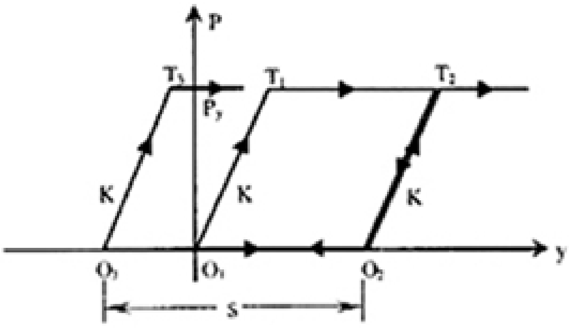
Double layer grids are special systems consisting of two upper and beneath handed parallel layers that the bond of these two layers is being carried out by flanked or vertical member and distribute the loadings' transmitting as three dimensions in this case. These kinds of structures have been utilized for having several advantageous such as the lightness, high rigidity, easy set up, and coverage of vast spaces in decades ago. These spatial trusses have usually an uncertain degree of high static and based on this, it is imagined that after the destruction of the member of a part of structure, other parts can easily absorb the distributed forces tolerating even high loadings in this regard. But experimental observations showed that the destruction of the double layer grid of Hartford sport saloon as well as the results of various experiments carried out confirm the correctness of this hypothesis in this case. Different factors such as strike, materials and connections damages, bending of under pressure member may lead to the destruction of the structure. In practice, this kind of destruction without any increase in the external loadings makes a distributive loading in the internal forces of the same structure; as a result, a member may be destructed and then makes high distributions in the related forces. Hence, the destruction is being distributed and published in all over the structure. This phenomenon is called the progressive collapse or Domino Effect.

In order to avoid this phenomenon, many researchers have been carried out with various planning methods using different tools for Ductility and Energy Absorbing of double layers of the structures for decades; one of these methods is subjected to the application of Force Limiting device (FLD) as much effective in preventing the progressive collapse in different models of double layers' grids. The main application of these tools is the formation of the shape of truss members and also the rapid depletion of energy of dynamic loads [1].

In this research, there has been represented a method that the tensioning member and bending of the member have been avoided and the ability of the structure is being increased against any unconventional and eccentric forces and loadings. The strategy of planning is that the structure is permitted to get exposed to and huge deformations vertically on the structure plate against the explosion loadings. These deformations are conducted to eliminate numbers of beneath layer of tensioning part. Then, the control of double layers strike response using different destructing energy and Tube Inversion Device (TID) has been evaluated in this regard. (Fig. 1). This new destructing system absorbs the internal energy through inversing a tube that is made of deforming material. This system has high potential absorbing capacity and the degree of delivered loading and its stiffness get fixed up to the end of its capacity [2]. in this research, dynamic analysis method has been used to evaluate the behavior of double layers' grids along with the determination of Explosion Loading. In this dynamic method, the nature of the dynamic phenomenon is directly considered in the related analysis.



(a) : Tube Inversion Device



(b) : Deformation-Force Curve of TID

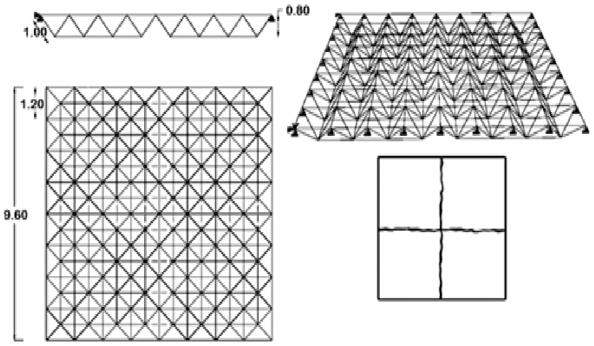
Fig. 1 Diagram of deformation-force and complete figure of TID

Generally, the most important targets of the research are as following:

1. Study of nature and how-to-work of double layer grids performance under the unconventional loads using the limited element.

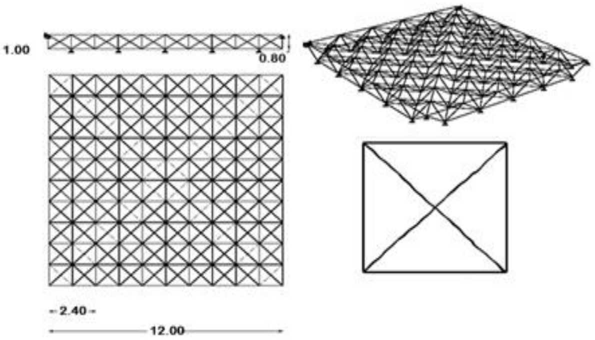
2. Evaluation of destructing energy systems of TID impact in recovering the structure stable deformation.

3. Assessing the economic aspects of this method and comparing other methods.



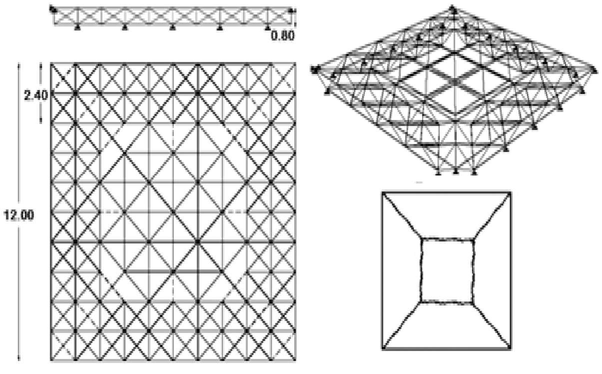
PI Assumptive failure scheme

(a) : SOS Configuration



MU Assumptive failure scheme

(b) : DOD Configuration



CO Assumptive failure scheme

(c) : COM Configuration

Fig. 2 Contextual structure and figure of the sample models with assumed rupture

The applied strategy in this research is that the selected models are let deformed largely but do not permit tensions to exceed of the material delivery tensions in the member of the structure. In this research, three types of deformations conducted on three models of double layer grids have been considered. (Fig. 2).

2 ANALYSIS MODELING OF SAMPLE DOUBLE GRID STRUCTURES

The planning of the cross-sections is carried out based on allowable tension method in this study [3].

2.1. Model of sample (SOS)

This is a double layer grid structure which has been established on a squared-figure along with Edge Supporting and Cornice shaped arrangement. The number of the points is 8*8. Also, this structure has 9.6m threshold length and 0.8m depth. The eliminated elements have been shown as dotted lines to reach to the PI failure schema in the structure plan. The specifications of sections and dimensions as well as the designed elements for the related structure have been given in table 1.

Table 1 Specifications and dimensions of SOS model elements

Name of member	Type of member	Dimensions of member (thickness of diameter) (mm)	Surface of member (cm^2)	Length of element (m)
T1	Empty, circle	3.6, 60.3	6.41	1
T2	Empty, circle	60.3, 4	7.07	1.2
T3	Empty, circle	4.5, 76.1	10.12	1.2

2.2. Model of sample DOD

This structure is a special double layer structure. The combination of the meshes is 5*5 in this structure. The arrangement of these meshes is different in the compressive and stretching layers in this structure. Also, this structure has 12 m length in threshold and 0.8 m depth. The eliminated elements for reaching to the failure schema of Mu have shown as dotted lane in this structure plan. The specifications of the cross section and elements dimensions have been shown in table 2.

2.3. Sample model of COM

This is a special double layer structure consisting of square and diagonal-shaped with lateral anchors. The combination of the meshes is 5*5 in this structure. The arrangement of the meshes is different in the compressive and stretching layers in this structure. (Fig. 3). Also, this structure has 12 m length of threshold and 0.8 m depth. The eliminated elements for reaching to the failure schema of Co have been shown as dotted lane in this structure. The specifications of the cross section and elements dimensions have been shown in table 3. In the related structures, steel material ST37 has been utilized in this case. This type of steel is established among the soft carbon steels and the maximum of the present carbon is between 0.25 and 0.29. This percent of carbon causes the steel, a moderate delivery tension and deformation or ductility in this regard. The specifications of this material have been shown in table 4 as following [3].

Table 2 Specifications of cross section and elements dimensions of the model DOD

Name of member	Type of member	Dimensions of member (thickness of diameter) (mm)	Surface of member (cm^2)	Length of element (m)
T1	Empty, circle	60.3, 5.6	9.62	1.44
T2	Empty, circle	127, 6.3	23.89	1.44
T3	Empty, circle	60.3, 5.6	9.62	1.7
T4	Empty, circle	108, 6.3	20.13	1.7
T5	Empty, circle	60.3, 5.6	9.62	2.4

Table 3 Contextual structure and shape of layers in COM

Name of member	Type of member	Dimensions of member (thickness of diameter) (mm)	Surface of member (cm^2)	Length of element (m)
T1	Empty, circle	60.3 5.6	9.62	1.4
T2	Empty, circle	60.3 5.6	9.62	1.7
T3	Empty, circle	108 6.3	20.13	1.7
T4	Empty, circle	60.3 5.6	9.62	1.8
T5	Empty, circle	60.3 5.6	9.62	2.4
T6	Empty, circle	108 6.3	20.13	2.4

Table 4 Specifications of consumptive material

Specifications of material planning		Specifications of material analysis				
Progressive tension (Fy) (N/m^2)	Failure tension (Fu) (N/m^2)	Density of volume (w) (kg/m^3)	Weight of volume (w) (kg/m^3)	Elasticity module (Ec) (N/m^2)	Powasion coefficient (v)	Cutting module (G) (N/m^2)
$2.4*10^8$	$3.6*10^8$	800	7850	$2.1*10^{11}$	0.3	$7.85*10^{10}$

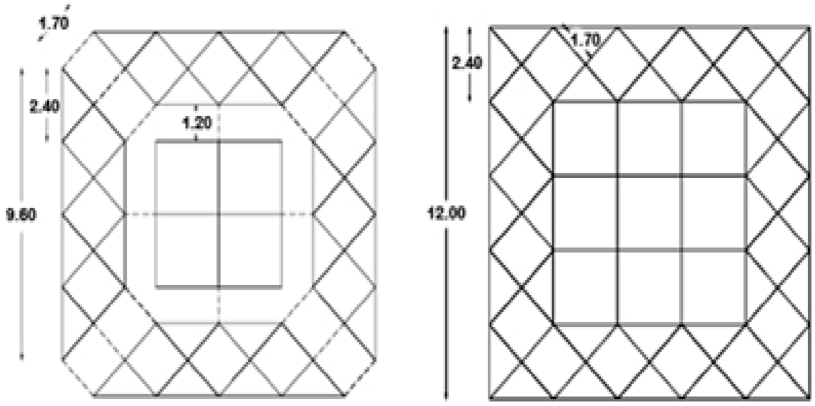


Fig. 3 Contextual structure and figure of the sample models COM

3 MODELING THE MEMBERS OF FORCE LIMITING DEVICE (FLD)

The main application of this tool is to make ductility in truss members as well as the destruction of rapid dynamic loadings energy [4]. In Fig. 4 and table 5, the specifications of FLD and TID have been applied for the under-study structures in terms of axial elastic stiffness and delivery force.

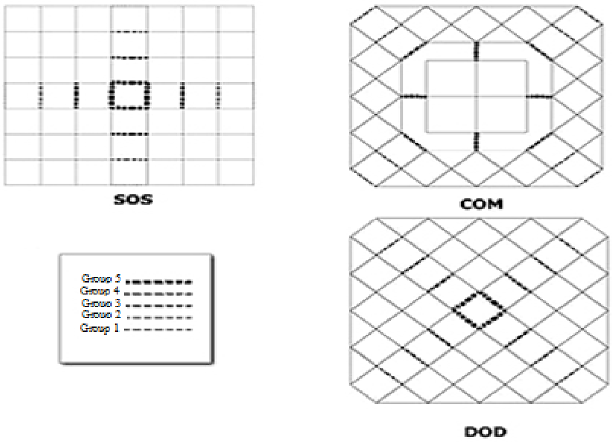


Fig. 4 Sort of FLD and TID groups in the tensile layer models

4 MODELING OF TID

The sophisticated feature of this system is the diagram of force-ductility; this device is affected by the stretching force than other devices having lower delivery point and its plastic territory is considered as horizontal lane. In Fig. 5 the diagram of force-ductility of TID affected by the stretching force has been shown**.**

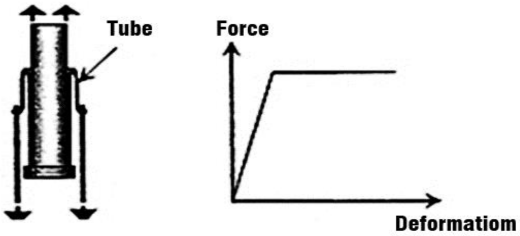


Fig. 5 Diagram of force-ductility in TID under the affection of stretching force

If the compressive force is produced in the system, the type of applied system in this device avoids producing the internal compressive force in different parts of the system [5]. In table 5, the specifications of TID have been evaluated for the under-study structures. Of course, the degree of stiffness, axial elastic and delivery force have been also assessed in this regard.

Table 5 Specifications of FLD and TID applied in the sample structures

Type of dead point	FLD				TID				
	Specifications				Specifications				
Name of structure	Group	Elasticity stiffness (KN/m)	Delivery force (KN)	Length of element (m)	Number of element	Elastic stiffness (KN/m)	Delivery force (KN)	Length of element (m)	number of element
SOS	Group 1	1000000	20	1.2	4	1000000	10	1.2	4
	Group 2	1000000	40	1.2	4	1000000	20	1.2	4
	Group 3	1000000	60	1.2	4	1000000	30	1.2	4
	Group 4	1000000	96	1.2	4	1000000	48	1.2	4
DOD	Group 1	1000000	30	1.7	4	1000000	15	1.7	4
	Group 2	1000000	50	1.7	4	1000000	25	1.7	4
	Group 3	1000000	100	1.7	4	1000000	50	1.7	4
	Group 4	1000000	180	1.7	4	1000000	90	1.7	4
	Group 5	1000000	250	1.7	4	1000000	125	1.7	4
COM	Group 1	1000000	20	1.7	8	1000000	10	1.7	8
	Group 2	1000000	40	1.7	4	1000000	20	1.7	4
	Group 3	1000000	80	1.2	4	1000000	40	1.2	4

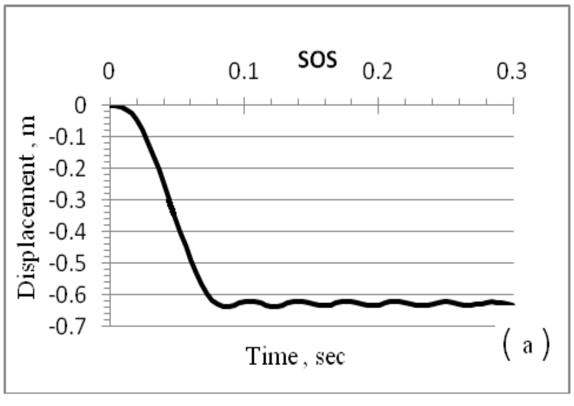
In continue, analyses of these dead points were substituted of FLD; then, the performance of the structure was evaluated for these cases as well. Thus, the number of TIDs with FLD should be applied equally in the related structures. For the process of compensation and ductility in the modeled structures, TIDs should be equipped with another device in a compressive way. Hence, equipping TID with a spring makes the related process possible. Because, TID dead points never show any resistance against the compression and the installed spring can compensate the whole structure ductility forced by its elastic deformations. The specification of the related spring has been shown in table 6.

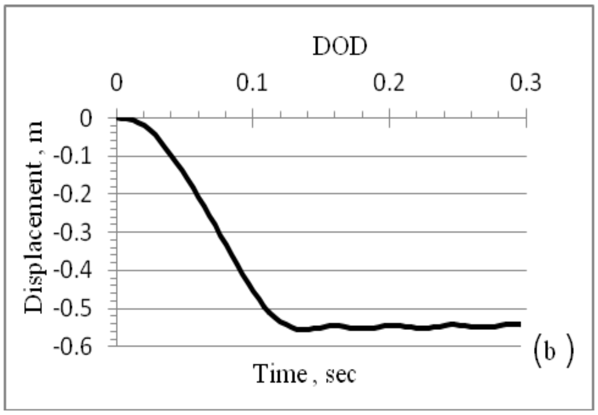
Table 6 Specification of installed spring to TID

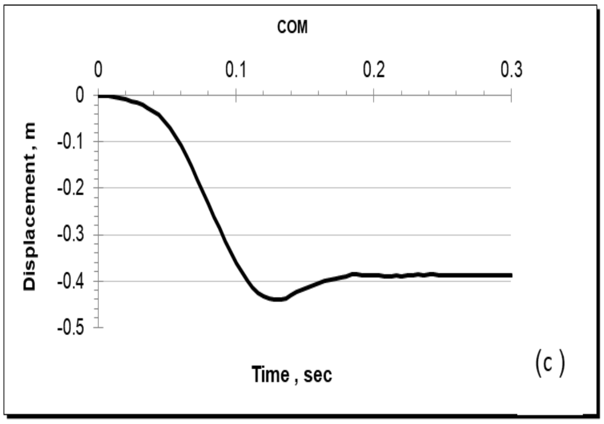
Name of structure	Group	Elasticity stiffness (KN/m)	Length of element (m)
SOS	Group 1	25	1.195
	Group 2	50	1.195
	Group 3	100	1.195
	Group 4	200	1.195
DOD	Group 1	25	1.695
	Group 2	50	1.695
	Group 3	100	1.695
	Group 4	150	1.695
	Group 5	300	1.695
COM	Group 1	25	1.695
	Group 2	50	1.695
	Group 3	100	1.195

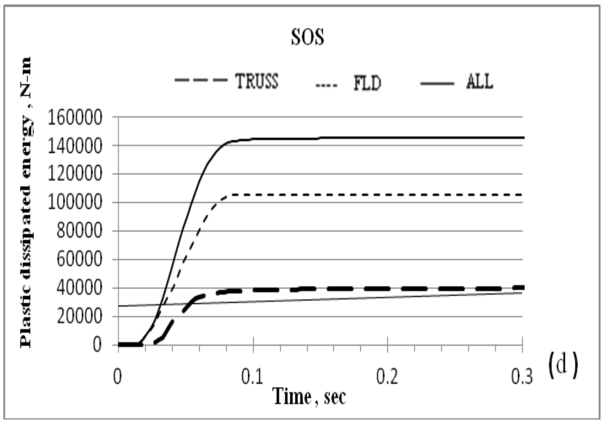
5 STUDY OF ANALYSIS RESULTS OF STRUCTURES EQUIPPED WITH FLD

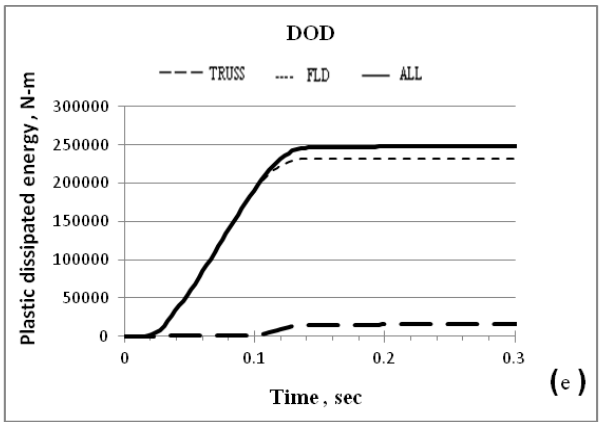
In continue, we try to carry out the impact of FLD on structures deformation in the sample. In Fig. 6 the impact of FLD on the central grid deformation is introduced for explosive loading and destructing plastic energy with FLD for 0.3s in this regard.











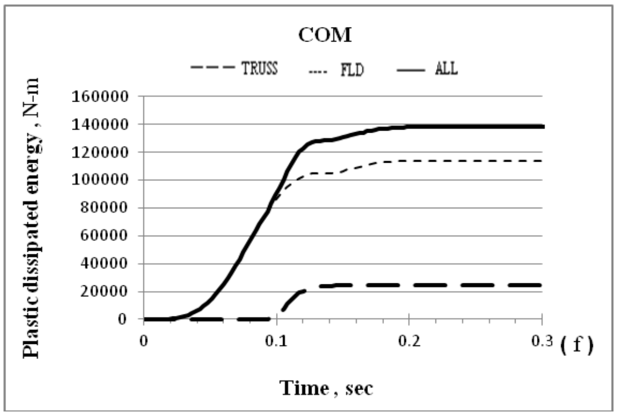
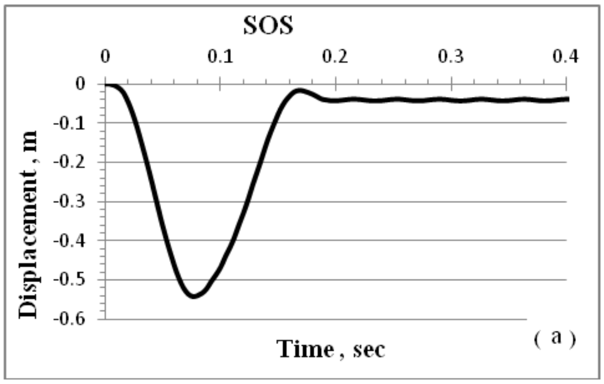


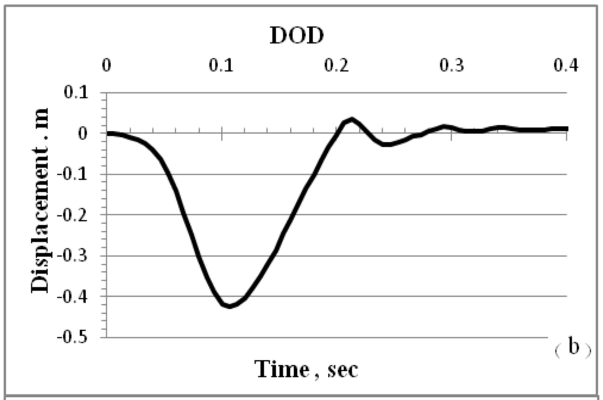
Fig. 6 Periodical history of structure central grid deformation with FLD:

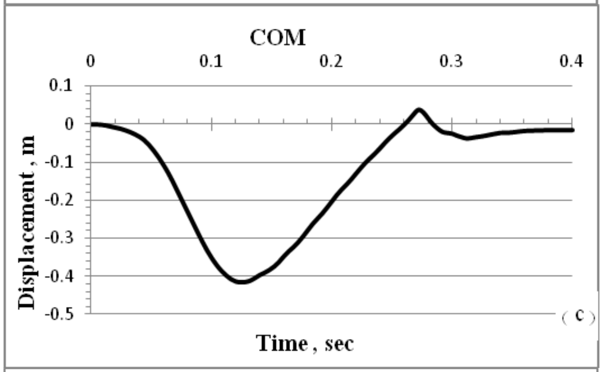
(a): Structure SOS, (b): Structure DOD and (c): Structure COM Destructing plastic energy with FLD for 0.3s: (d): Structure SOS, (e): Structure DOD and (f): Structure COM

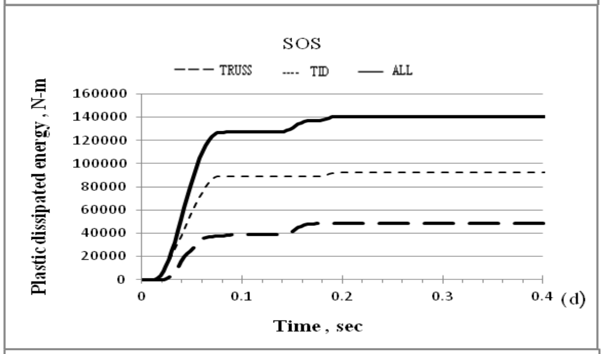
6 STUDY OF STRUCTURES RESULTS EQUIPPED WITH TID

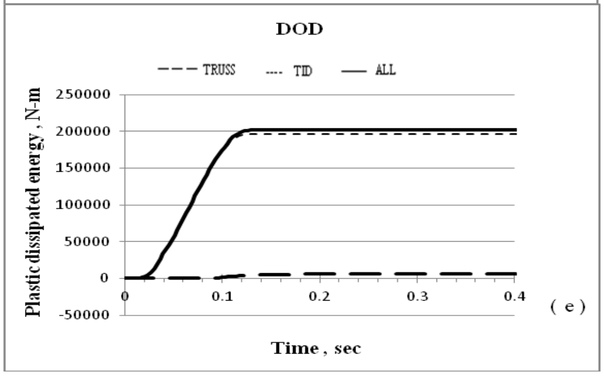
In this section, we like to carry out the impact of introduced TID and the results of sample structures behavior equipped with FLD. In Fig. 7, the impact of TID on the central grid deformation of the sample structures has been introduced for the explosion loading and destructing plastic energy with TID in 0.4 s in this regard**.**











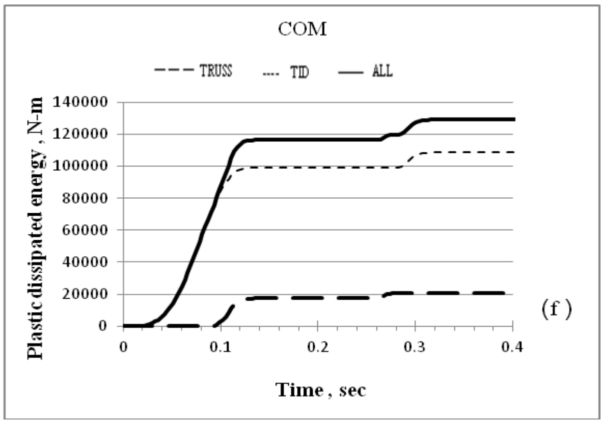
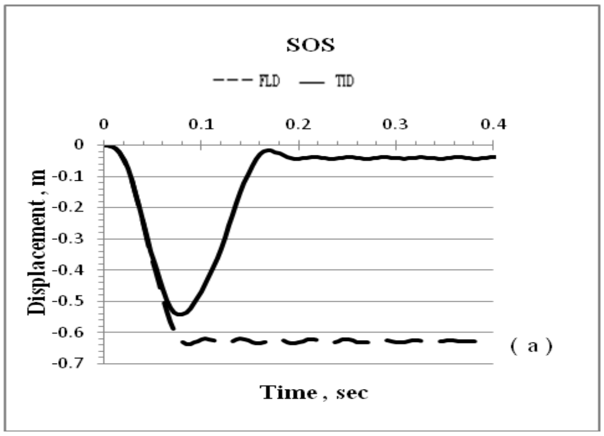


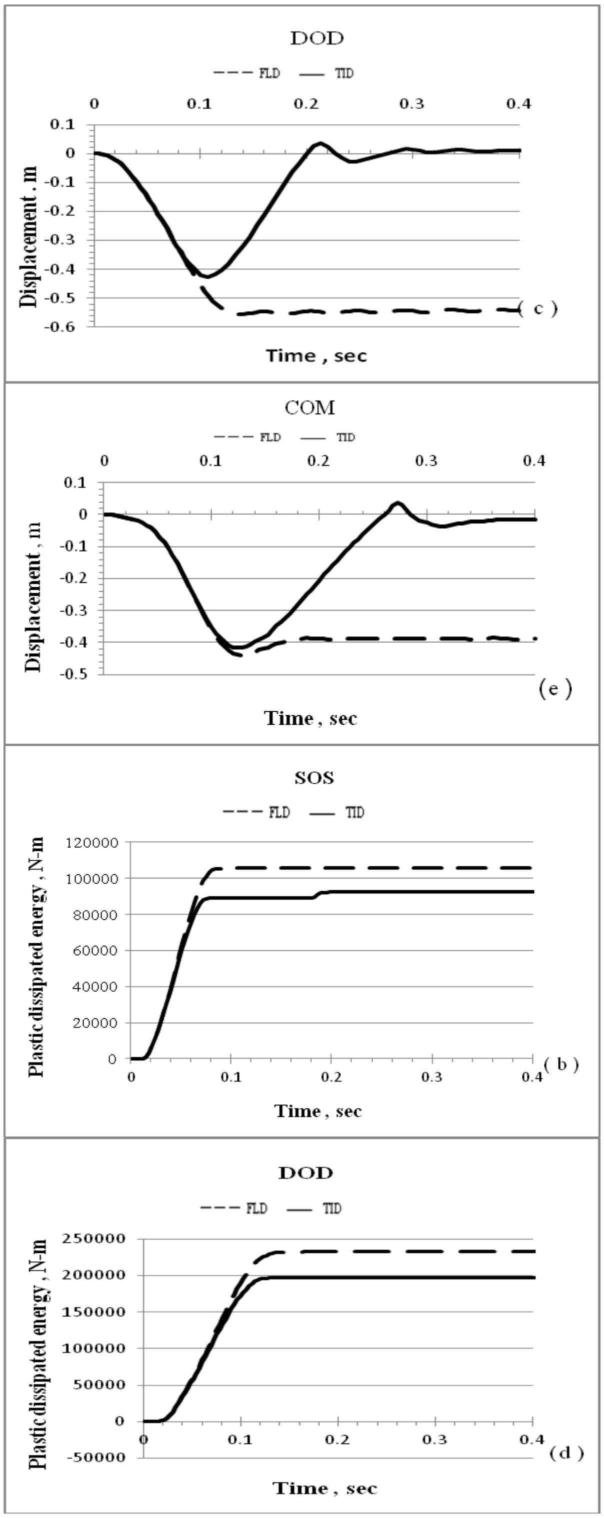
Fig. 7 Periodical history of the central grid deformation of structure with TID:

(a): Structure SOS, (b): Structure DOD and (c): Structure COM, Destructing plastic energy with TID for 0.4s:
(d): Structure SOS, (e): Structure DOD and
(f): Structure COM

7 STUDY OF STRUCTURES RESULTS EQUIPPED WITH TID

In this section the comparison of the dead points impacts on the central grid deformation of the models has been discussed. In Fig. 8 the comparative periodical history of the central grid vertically has been shown in the application of two kinds of dead points for the sample structures. Because we want to review the dead points on tensions in 0.4 s, destructing plastic energy has been compared by two dead points in the related structures that the results were given in Fig. 8.





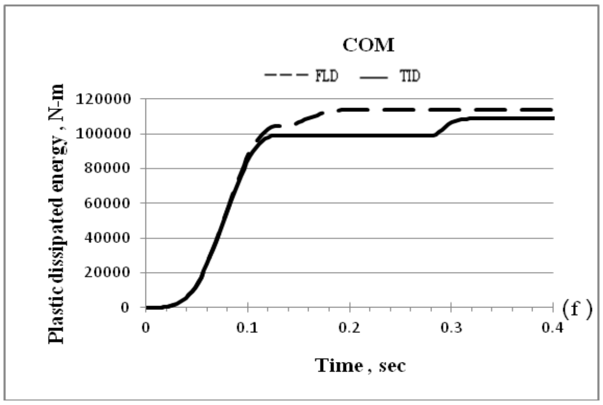


Fig. 8 Periodical history of the central deformation of structure with two types of dead points:

(a): Structure SOS, (c): Structure DOD and (e): Structure COM, Destructing plastic energy by FLD and TID for 0.4s: (b): Structure SOS, (d): Structure DOD and (f): Structure COM

8 STUDY OF MODELS RESULTS WITHOUT DEAD POINT MOOD AND WITH TID

In this section, we carry out the comparison of the structures performance in the model without the dead point and with TID. According to carried out studies, in table 7, the weight of the sample structure has been assessed in the situation of without dead point and with TID.

Table 7 The weight of sample structures without dead point and with TID

Name of structure	Without dead point (kg)	Equipped with TID (kg)	Percent of weight reduction
SOS	3833	2791	27%
DOD	8630	5954	30.5%
COM	8443	5964	29.3%

As it shown in table 7, it is observed that the application of TID in sample structures causes to the harsh decrease of the weight and as a result, the application of the element can be economically beneficial in these structures due to the high expenses of TID [2].

9 CONCLUSION

According to obtained results from the analysis, it is observed that the performance of TIDs is better than FLD in these structures. The advantageous of using TID in the sample grid structures are highly introduced compared to FLD in the process of deformability of these structures. Because, during returning of the structure ductility, the elements of TIDs do not show any preventions at all in this case; based on this, it is observed that the application of TID is highly efficient in comparison to FLD among the deformation indices; the most important results of these carried out studies are based on the behavior of double layers' grids against the explosion loading as following:

1. In double layer grids, the method of direct assumptive delivery and the application of a dead point along with this lane are more effective.

2. By the use of TID in tensional layer of double layer grids, any bending of the compressive member of the structure is prohibited due to the increase of the length of the elements and deformations of the related structure.

3. The application of TID can reduce about 96.4% of the deformations and 15.8% at the maximum deformation of the structure in the double layer grids with environmental anchors in elastic situation.

4. The application of energy dead points in the structure tensional layer causes to the reduction of 213% of explosive loading.

5. The application of energy dead points in the structure tensional layer of the double grids caused to the reduction of 28.9% of the structure weight in this regard.

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