Research Journal of Engineering & Technology. Vol., 1 (1), 1-12, 2024
Available online at http://www.rjetjournal.com
ISSN 2149-3340 ©2024

The Impact of Tube Inversion Device (TID) in the Recovery of Two Layers Nets Response and Space-Frame

Hadi Zarintala[1*], Saeed Monir[2], Alireza Nariman Jahan[3], Mehdi Darvish Hashemi[1]

[1]*Department of Civil Engineering, Bonab branch, Islamic Azad University, Bonab, Iran*
[2]*Department of Civil Engineering, Urmia University, Urmia, Iran*
[3]*Department of Civil Engineering, Maragheh branch, Islamic Azad University, Maragheh, Iran*

[*]Corresponding Author Email: h.zartala@hotmail.com

Abstract: Studies have shown that the space-location structures do not show suitable resistance against the unconventional and eccentric loads rapidly due to the existence of Dynamic Snap Through phenomenon in this regard. This is happened due to the lack of structure's ability in rapid achieved forces in the structure local destruction. Reaching to high resistance requires the structure high potential member against these loadings. Of course, this also requires high expense. In the present study, using a dead-point along with Tube Inversion Device (TID) and a special planning method not only prevents the high speed impact of loading, but also it reduces considerably the high weight of the structure acceptably in this case. Because, the reduction of a structure weight requires an increase of member thickness to be slim and for the reason, the axial force on the member is decreased as well. Therefore, in planning of these structures, it is struggled to conduct the main part of the forces over the structure towards the dead-point elements based on the delivered lines. 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 and TID 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: Force limiting device, Energy destructor of inversed tube, Nonlinear dynamical analysis, Explosion loading, Double layer grids, Dynamic jumping.

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 researches 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 (Sheidaiee, 2001).

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 as 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 (Figure1). 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 (Nariman Jahan, 2009). 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.

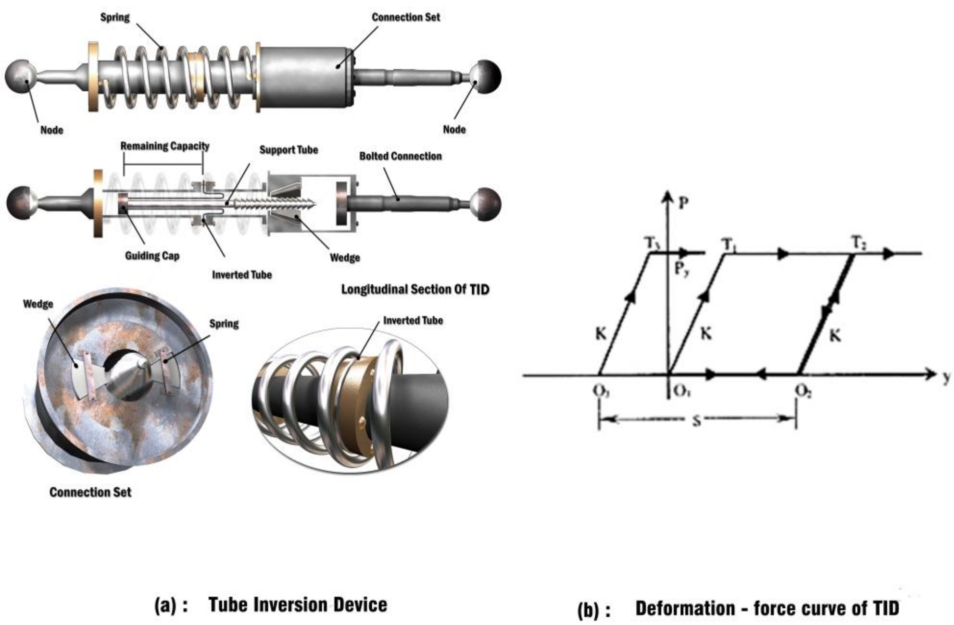

Figure 1. Diagram of deformation-force and complete figure of TID.

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

1- Study of nature and the function 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
4- Study of energy destructive systems of TID in the waste of explosive loading energy entered into the structure and its comparison with function of FLD

The applied strategy in this research is that the selected models are let deformed largely but 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 (Figure 2).

As stated before, this action is done by eliminating some parts of the tensioning layer member; by this planning, the related structure is divided into some parts so that every parts have elastic deformations against the forces in compare to total leap as it is negligible in this case (2).

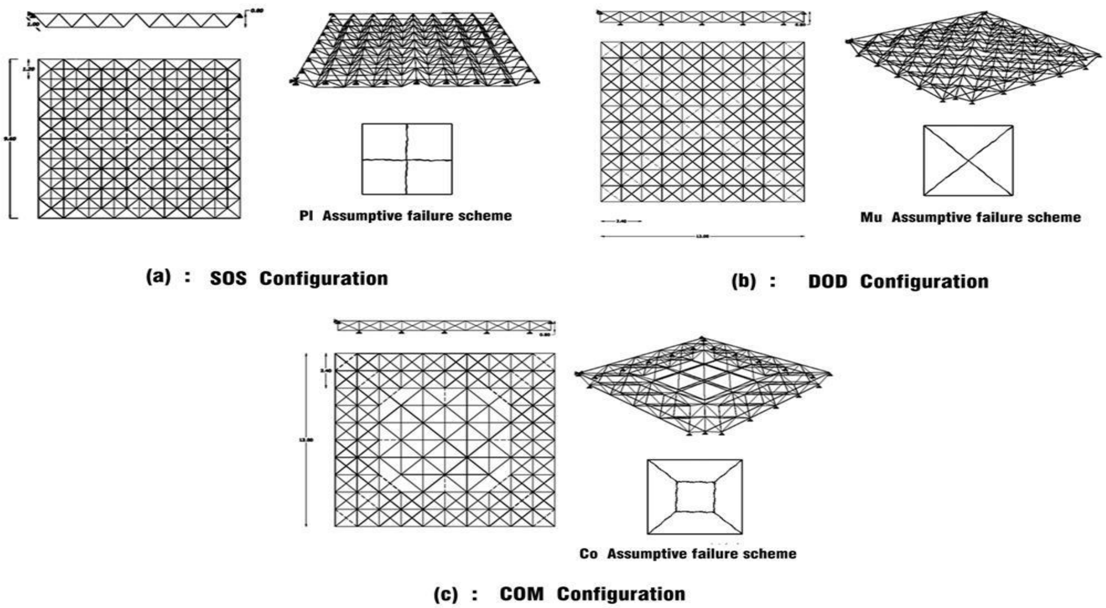

Figure 2. Contextual structure and figure of the sample models with assumed rupture.

Analysis modeling of sample double grid structures

The planning of the cross-sections is carried out based on allowable tension method in this study. In this study, the elastic behavior of composing members has been considered so that in planning of a structure, it is not allowed the present elements to enter into the plastic area (except dead-point elements). In a computer-based planning of the structures, it is necessary for an engineer to specify and determine the early cross sectional dimension. Since, there is no any rolling in the double layer grids, hence the selection of early cross sections is highly free (Tahooni, 2006). during the process of planning, the ideal cross sections are obtained by the use of test-error method for the related structures. The members of the truss have been planned like a two-sided joint without any end bending stiffness. According to figure 2, for every schemes of the assumptive failure, Mu, Co as a double layer grid has been considered. These structures have been modeled accurately to reach to the related assumptive failure schema.

Model of sample (SOS)

This is a double layer grid structure 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 (cm2)	Length of element (m)
T1	Empty circle	3.6 60.3	6.41	1
T2	Empty circle	60.3	7.07	1.2
T3	Empty circle	4.5 76.1	10.12	1.2

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 the compressive and stretching layers in this structure. Also, this structure has 12m length in threshold and 0.8m 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.

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 (cm2)	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

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. (Figure 3). Also, this structure has 12m length of threshold and 0.8m 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.

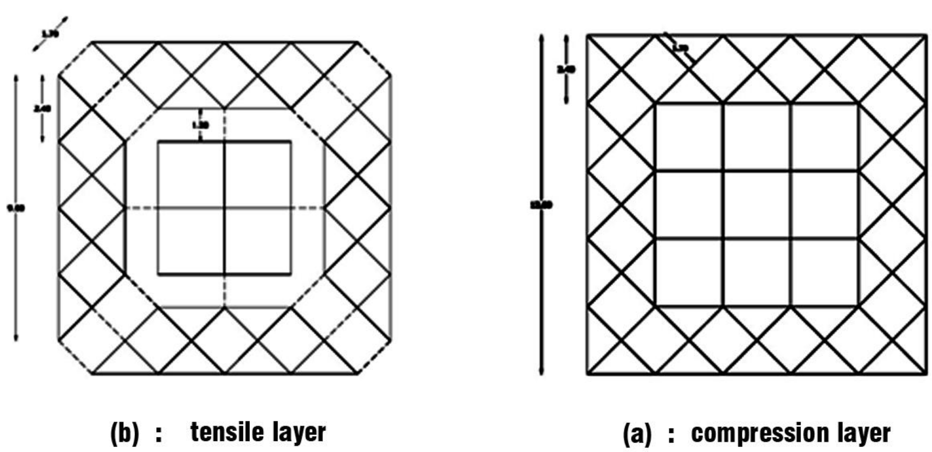

Figure 3. Structure and shape of sample models with schema of assumptive detach.

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 (cm2)	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

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 has a moderate delivery tension and deformation or ductility in this regard. The specifications of this material have been shown in table 4 as following.

Table 4. Specifications of consumptive material.

Specifications of material planning		Specifications of material analysis				
Progressive tension (Fy) (N/m2)	Failure tension (Fu)(N/m2)	Density of volume (w) (kg/m3)	Weight of volume (w)(kg/m3)	Elasticity module (Ec) (N/m2)	Powasion coefficient (v)	Cutting module (G)(N/m2)
2.4*108	3.6*108	800	7850	2.1*1011	0.3	7.85*1010

Explosion loading

In this case, the time of loading is very short and it usually is based on milliseconds. At the end of the explosion phenomenon, a negative strike is being made causing the process of suction. The maximum pressure is followed by the degree of TNT explosive material and the third power of the distance. For an explosive danger based on the weight of the material and the distance, the maximum pressure of the strike and the reflective wave of the same strike and other parameters such as the speed of strike and time of reaching the wave can be given by charts of TM5-1300 or using suitable software of ATBlast can also be extracted in this regard.
The periodical history of explosive wave pressure is often represented by the equation of Frielander as following:

Equation 1:

$$p(t) = p_0 + p_s\left[1 - {}^{t}/_{T_s}\right]\exp\left\{-b\,\frac{t}{T_s}\right\}$$

In this relation, t is time, ‘ p_o as atmospheric pressure, Ps extra maximum pressure, Ts the time of positive phase and b is the fixed positive called as wave-shaped parameter depending on the maximum pressure in this regard.

The explosive loading on the under-study structures is selected as triangle strike loading that has shown in figure 4; this loading along with the frequent time 0.03s is entered into the top grids of the structure (Vahedi, 2008). the process of loading has been started from 0.05s for studying better results in this case. The strike loading of the maximum pressure to top central grids has been considered Fy = 30000 N; this degree of the loading is obtained with 10kg explosive material TNT in 20m distance of the structure. The degree of this force and periodical changes have been measured by the help of ATBlast software being introduced by Amplitudes to ABAQUS software in this regard.

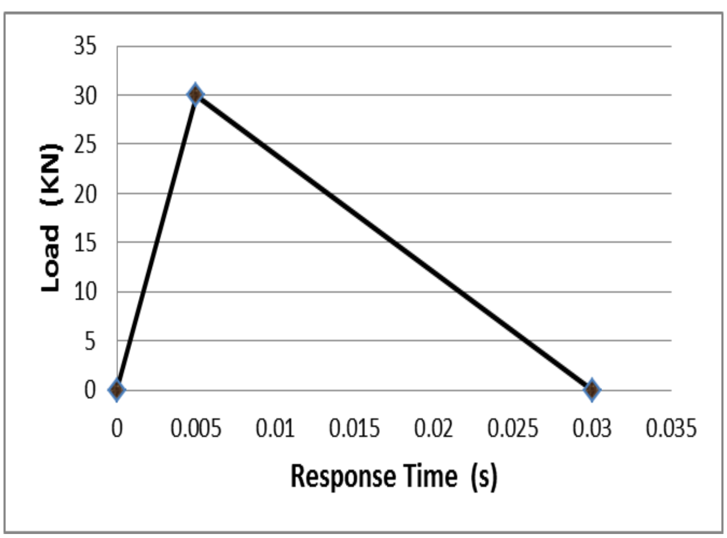

Figure 4. Explosive loading as triangle loading.

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 (Hesari et al., 2007). in 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.

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

Type of dead point		FLD				TID			
		Specifications							
Name of structure	Group	Elasticity stiffness	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 figure 5 the arrangement of different groups of FLD and TID has been introduced that these have been also shown in table 5 for the under-study models. In this figure only the structure’s stretch (lower layer) has been specified.

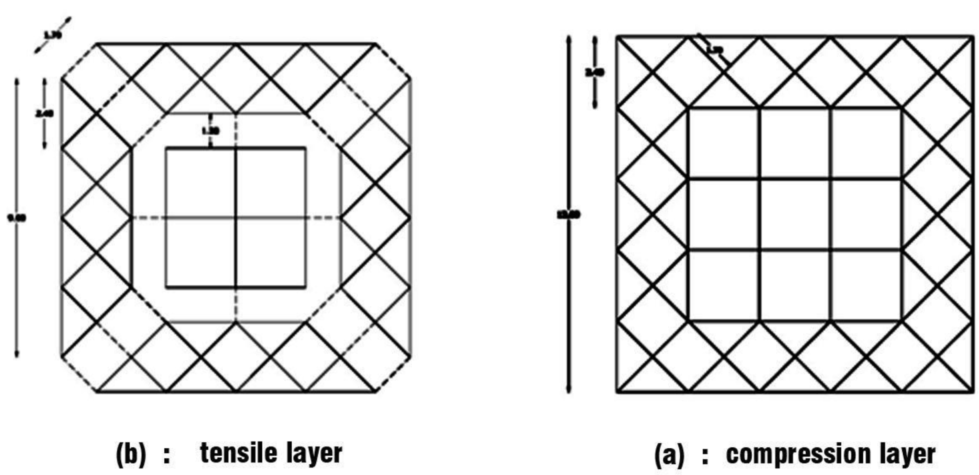

Figure 5. The arrangement of different groups of FLD and TID.

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 figure 6 the diagram of force-ductility of TID affected by the stretching force has been shown.

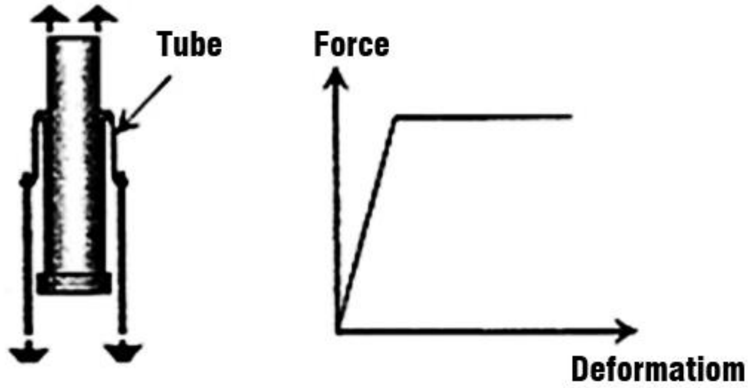

Figure 6. Diagram of force-ductility in TID under the affection of stretching force.

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. (6). 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. 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	Stiffness (KN/m) elastic	Length of spring (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

Study of nonlinear dynamic analysis results

In analysis of structures dynamics, the movement equation should be represented as a mathematic relation after the determination of structure analysis model using specified physical regulations. Generally, a usual nonlinear differential equation is applied in dynamical analyses. It can be as equation (2) as following:

$$m\ddot{u} + f(u, \dot{u}, t) = 0$$

In these differential relations, the tensional force and dead force have nonlinear relations along with deformation and device speed, respectively. Solving this kind of mathematic equation is usually complicated requiring digit methods for reaching to a suitable answer. In this research, the method of Explicit has been applied to reach to the related answer as a part of Abaqus software elements (Monir, 2004).

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 figure 7 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.

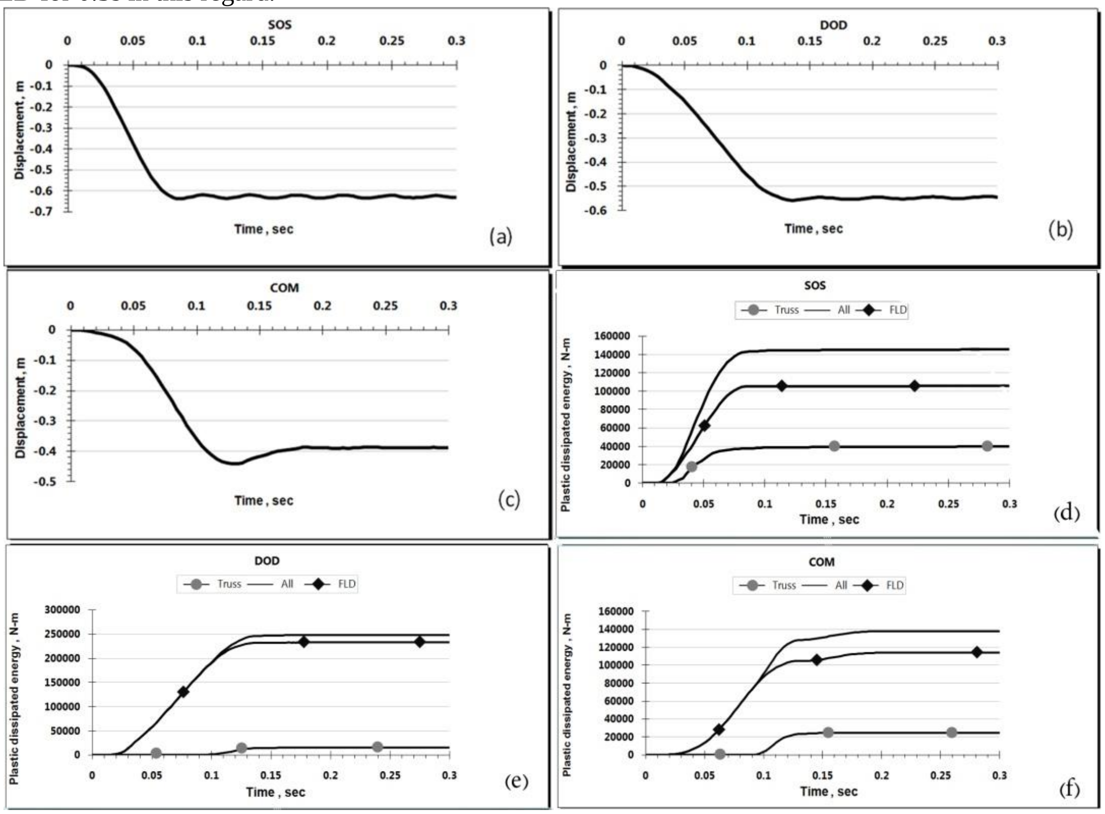

Figure 7. Periodical history of structure central grid deformation with FLD.
Structure C, (DOD): structure b, (SOS): structure a (in time of 0.3 FLD), destroyed plastic energy with COM: structure f, (DOD): structure e, (SOS): structure d

According to figure 7, in sample structure SOS (diagram a), the structure with FLD 63cm stable deformation, in structure DOD (diagram b) 54cm deformation and structure COM (diagram c) 38cm deformation will be experienced in this cases. Maximum deformation of the models is 63, 55 and 44cm, respectively. According to the obtained results, the maximum tension in structure SOS is 0.028s and $1.52*^{10^8\ N/m^2}$ the maximum tension in structure DOD is 0.032s and $2.38*^{10^8\ N/m^2}$ and the maximum tension in structure COM is 0.1s and $2.19*^{10^8\ N/m^2}$ while the structure has not experienced its deformation yet. In diagram (d) figure (7), model SOS the degree of consumed energy is 144 KN per meter by the whole structure that about 72% of this energy has been established by FLD. Thus, only 28% of this energy is forced on the structure member and consequently the surface of the cross section is little designed in this structure. In diagram (e) Model DOD, the degree of wasted energy is 247 KN per meter that about 94% of this energy by FLD and only 6% of the same energy by truss has been absorbed. In diagram (f) Model COM the wasted energy is 138 KN per meter that about 82% of the energy by FLD and only 18% by truss has been absorbed.

Study of structures analysis 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 figure (8), 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 0.4s in this regard.

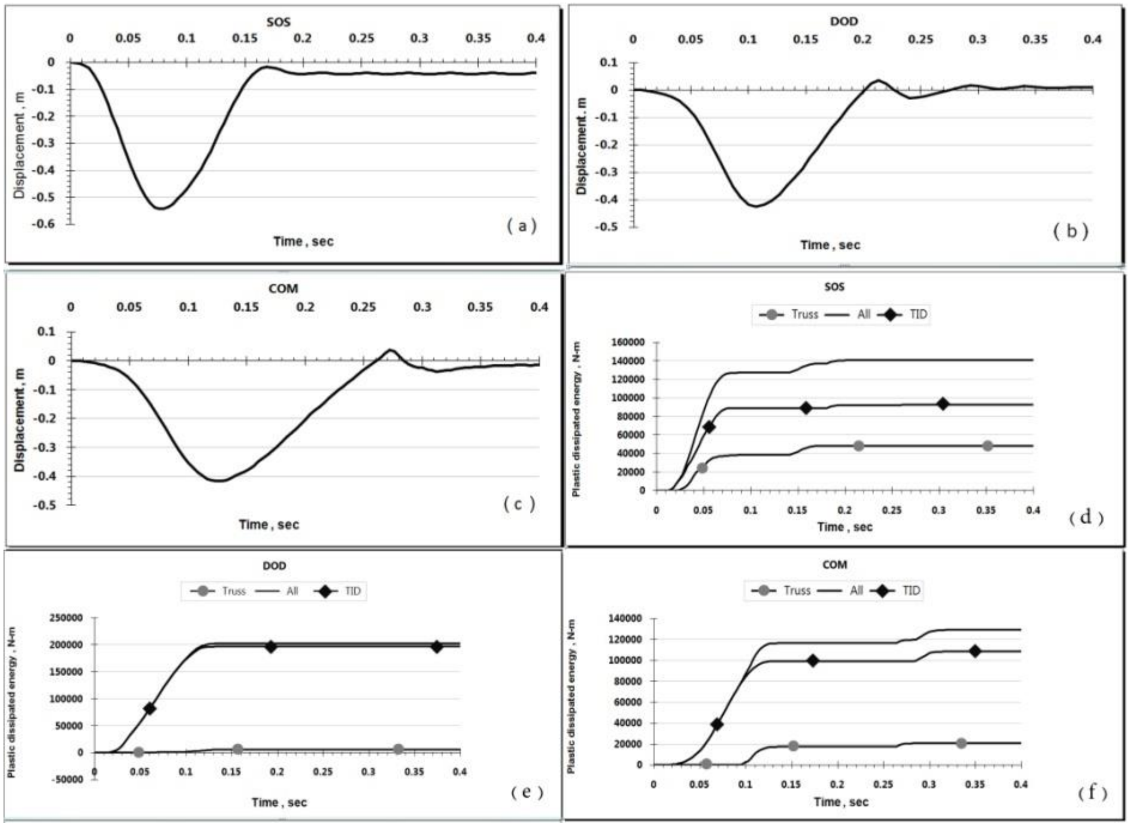

Figure 8. Periodical history of the central grid deformation of structure with TID.
COM: structure c, (DOD): structure b, (SOS): structure a (in time of 0.4 TID), destroyed plastic energy with COM): structure f, (DOD): structure e, (SOS): structure d

According to figure 8, in sample structure SOS (diagram a), the structure with FLD 4cm stable deformation, in structure DOD (diagram b) 1cm deformation and structure COM (diagram c) 1.5cm deformation will be experienced in this cases. Maximum deformation of the models is 54, 42 and 41cm, respectively. According to the obtained results, the maximum tension in structure SOS is 0.028s and 1.49*$10^8\ N/m^2$; the maximum tension in structure DOD is 0.036s and 2.35*$10^8\ N/m^2$ and the maximum tension in structure COM is 0.11s and 2.19*$10^8\ N/m^2$ while the structure has not experienced its deformation yet. In diagram (d) figure (8), model SOS the degree of consumed energy is 141 KN per meter by the whole structure that about 66% of this energy has been established by FLD. Thus, only 34% of this energy is forced on the structure member and consequently the surface of the cross section is little designed in this structure. In diagram (e) Model DOD, the degree of wasted energy is 203 KN per meter that about 97% of this energy by TID and only 3% of the same energy by truss has been absorbed. In diagram (f) Model COM the wasted energy is 129 KN per meter that about 85% of the energy by TID and only 15% by truss has been absorbed.

Comparison of Results

In this section the comparison of the dead points impacts on the central grid deformation of the models has been discussed. In figure (9) 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 0.4s, destructing plastic energy has been compared by two dead points in the related structures that the results were given in figure (9).

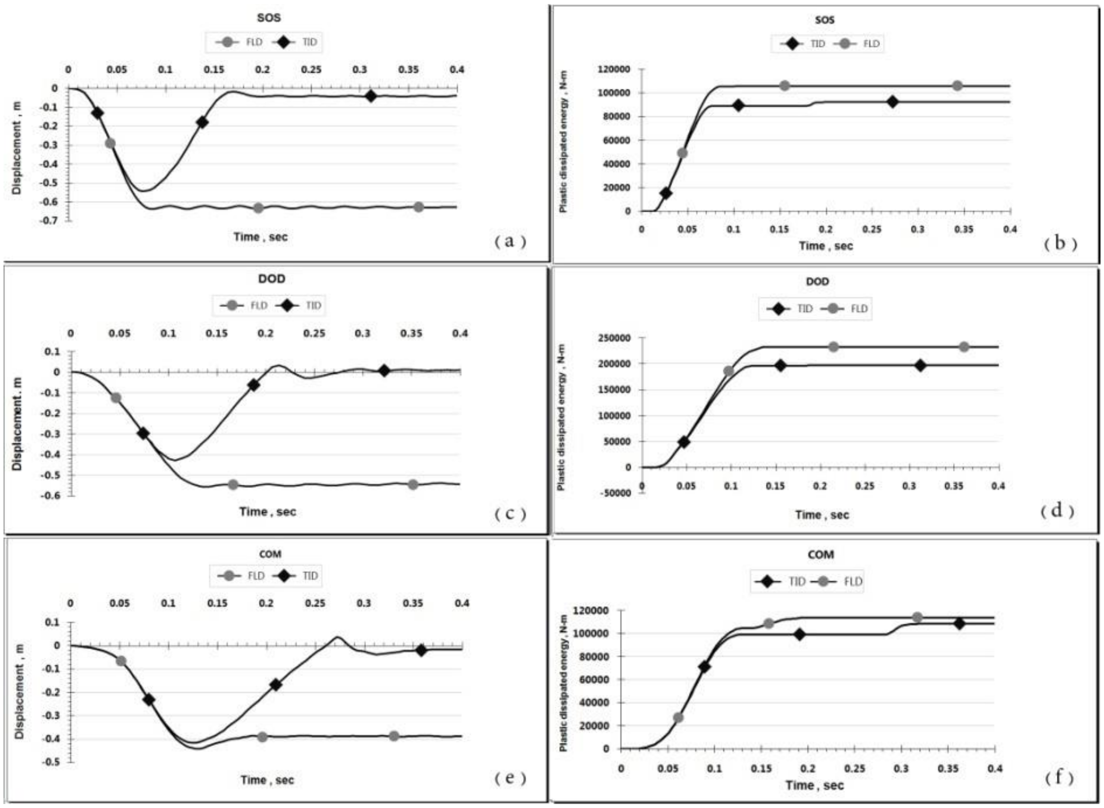

Figure 9. Periodical history of the central deformation of structure with two types of dead points COM: structure c, (DOD): structure b, (SOS): structure a (in time of 0.4 TID), destroyed plastic energy with COM): structure f, (DOD): structure e, (SOS): structure d

Figure (9) diagram (a): as it shown in the figure, using TID reduces the maximum deformation and stable deformation considerably in compare to the application of FLD in structure SOS while there is no found any change in the maximum period of deformation in both moods and this happens in 0.08s in this case. The application of TID reduces about 15.7% in the maximum deformation and 92.5% in the central grid deformation in this model. Although TID causes to the reduction of the structure deformation, the reason is that the maximum tensions do not have considerable impact in this regard. Because the maximum tensions happen in 0.028s and in this time, the structure has not experienced the maximum deformation and the maximum deformation of the structure happens at 0.08s in this case. And in this period, considerable energy is wasted by the dead point.

Figure (9) diagram (b):

The degree of the wasted energy by FLD is 105.6 KN per meter and the degree of destructing energy by TID is about 92.4 KN per meter. this difference in wasted energy is due to the spring elastic stiffness performance adding to early TID in both dead points. In FLD, the whole wasted energy has been carried out frequently due to the lack of compensation of plastic length increase in dead point at 0.087s while the same process in TID is being carried out in two alternative vibrations of the structure. The high part of this energy in 0.081s and low section in 0.2s is absorbed in this regard. The performance of TID in this structure can be represented; the related dead point loses its longitudinal capacity when receives tensional force; thus, main part of the energy is wasted by this time in 0.081s; then, in returning time of the deformation in structure, TID prevents any compressed force by releasing its connective hangers and in addition to the compensation of the length increase, it will be reduced due to its deformation in an inverse orientation of loading (structure vibration). Now, in return time of the deformations 0.2s, TID will be again activated absorbing another section of the energy approaching closely to early length in this case. Hence, the two-steps of the energy waste can be devoted to the performance of the spring in this structure.

Figure (9) diagram (c): The application of TID in model DOD causes to the reduction of 25% at the maximum deformation and 102% reduction in the stable deformation of the central grid; so, the stable deformation of the structure is being 1cm in the inversed orientation of the loading.

Figure (9) diagram (d): The degree of wasted energy by FLD is 232.4 KN per meter and degree of destructed energy by TID is about 196.9 KN/m. this degree of the difference in wasted energy is happened due to the type of two dead points and the performance of elastic spring have been added to early TID.

Figure (9) diagram (e): The application of TID in this model causes to the reduction of 6.8% in the maximum deformation and 94.8% reduction in the stable deformation of the central grid of the structure. Figure (9) diagram (f):

The degree of wasted energy by FLD is about 113.9 KN/m and the degree of destructed energy by TID is also about 108.8% KN per meter. In FLD the whole destructed energy has been carried out in an alternative vibration at 0.19s due to the lack of plastic length increase in the dead point while the wasted energy by TID is being done in two alternative vibration cycles of the structure. The high section of this energy is at 0.13s and the minimum part is fulfilled at 0.31s absorbed. Generally, the obtained results for the related models show the considerable recovery of the structure behavior in the mood of equipped with TID in this regard.

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. The economic situation is very important in planning of different structures significantly. Hence, in this section, it also is struggled to evaluate the weight of the structure without dead point and with TID; of course, in this study, the elastic behavior of composing member has been considered so that in planning of the structure, the present elements are not being permitted to get entered into the plastic area. For the reason, the cross section surface of some members is increased without the dead point. 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.

Discussion and 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 in compare 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 compare 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 is causing to the reduction of 28.9% of the structure weight in this regard.

References

Hesari M, Sardari H, Lotfallahi Yaghin, 2007. Modeling and analyzing with ABAQUS Software. Forouzesh Publication. [Publisher]

Nariman Jahan A, 2009. The impact of energy dead points in recovering double layer structures strike response. A thesis for M.A, Islamic Azad University, Maragheh Branch. [Publisher]

Sheidaiee M, 2001. The study of double layer grids behavior against progressive bending. A thesis for PhD, University of Tabriz, civil engineering faculty. [Publisher]

Tahooni Sh, 2006. Book of planning steel structures, 10^{th} printing, Elm o Adab Publication. [Publisher]

Vahedi J, 2008. The study of progressive dead points on the behavior of frames under explosive loading impact. 4^{th} conference of civil engineering. University of Tehran. [Publisher]