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Dynamic FEA and Simulation for A Series of Blast-Resist-door

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Abstract: A series of blast-resist-door were used widely. In order to know the behavior of the doors under blast load and verify the safety of the doors, dynamic finite element analysis and simulation are carried out with advanced FEA software, ANSYS/LS-DYNA and SAP. Contact surfaces are introduced to simulate the relation between the door leaf and doorframe, as well as the relation between the door hinges and bearings. Altogether 24 different load cases are analyzed to simulate various load conditions. For example, the difference between conventional explosive blast load and nuclear blast load are compared. Different doorframes are also discussed. And blasts that are much larger than the designed ones are analyzed to obtain the damage process of the doors and to get the safety margin to the original design. From the numerical computations, some special results are obtained, which are difficult from static analysis. For instant, the damage process shows that even if there is very large plastic strain in the door, the door may still be safe. So traditional allowable stress design method may be uneconomical. However, the numerical result also shows that the most dangerous situation for the door hinges does not consisted with designer's imagine, which means the original hinge design may be unsafe. Following conclusions are obtained from the whole simulation: (1) traditional static or quasi-static analysis has some limits in these special structures; (2) dynamic FEA is a cheap and convenient method for these structures; (3) contact analysis is important for dynamic simulation.

Keywords: blast-resist-door; dynamic FEA; contact analysis;

1 Introduction

A series of blast-resist-door were designed to have the bearing capacity of 500KPa, 1000KPa and 4000KPa, respectively. Hence, these doors are named as M0.5, M1, M4, respectively too. In order to know the dynamic behavior of these doors under blast load and estimate the real safety margin of the doors, dynamic finite element analysis (FEA) was carried out with the dynamic FEA software of LS-DYNA [1][2].

2 Details about the doors

The construction of the doors is shown in Fig. 1. The height of the doors is 2.13m, while 1.03m in width. The thickness of the door leaf and steel plate is various in different doors, which is list in table 1. There are two door latches and two hinges on the sides of the doors, which are used to bearing the pressure from outside.

Table 1 Door leaf parameters

Serial number	Door leaf thickness (/mm)	Steel Plate thickness (/mm)	Rib thickness (/mm)	Steel type
M0.5	71	6	4.8	Q235
M1	75	6	4.8	Q235
M4	142	8	5	16Mn

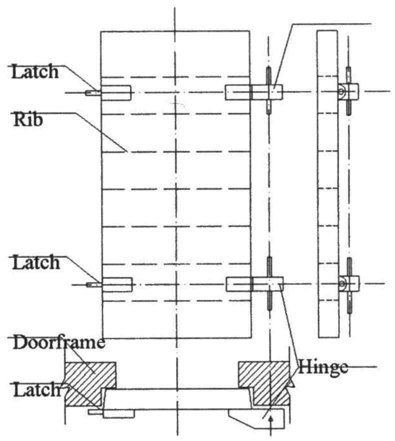

Fig. 1 Structure of the door

3 Finite element model

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The size of each door component in the FEA model is set up according to the drawing, strictly. The numerical models are adopted according to the real conditions, which are shown as following.

(1) Element type: the shell element called Shell 163 in LS-DYNA [2] is used to simulate the steel plates, the doorframe and the hinge bearings. The solid element called Solid 164 is used to simulate the door hinges and door latches.

(2) Material constitutive relationship: the constitutive relationship of Plastic Kinematic in LS-DYNA [2] is selected for steel material. The constitutive expression is shown as following:

$$\sigma_y = \left[1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{1/p}\right]\left(\sigma_0 + \beta E_p \varepsilon_p^{eff}\right) \tag{1}$$

The expression in the square brackets presents the influence of strain speed to the yield stress, while the expression in the parenthesis presents the plastic hardening model. If $\beta=1$, it is the isotropic hardening model. However, if $\beta=0$, then it is the kinematic hardening model. All the values of these parameters are shown in table 2:

Table 2 Parameters used in the model [3][5][6]

Parameter	E_0	υ	ρ	σ_y	β
Meaning	Initial Yang's Modulus	Poisson Ratio	Density	Yield Stress	Hardening Model Factor
Value	200×10^9Pa	0.27	7800Kg/m^3	310MPa (16Mn) 210MPa (Q235)	0
Parameter	C	P	ε_f	E_p	
Meaning	Strain speed Factor	Ultimate Strain	Hardening Modulus		
Value	40	5	0.25(16Mn) 0.35(Q235)	2×10^9Pa	

(3) Contact surface: there are two types of contact surface in this model. The first one is the contact between the door leaf and the doorframe. The second one is the contact between the door hinges and the door hinge bearings. The shapes of the contact surfaces are shown in Fig. 2.

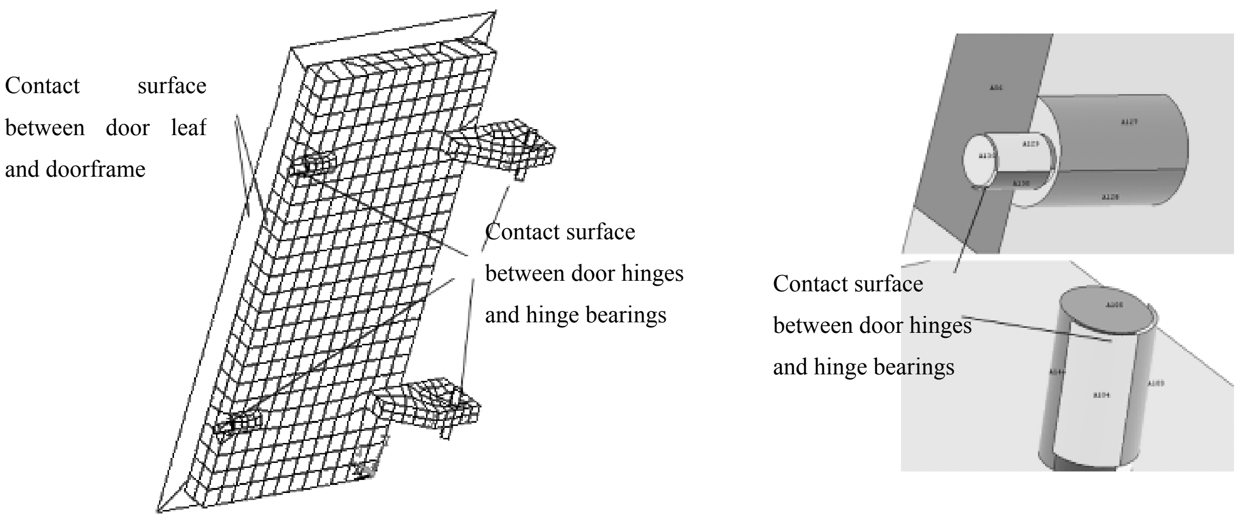

Fig. 2 Element meshes and contact surfaces

(4) Load conditions: because the blast load is indeterminate. Hence, in order to know the deformation and

damage of blast-resist-doors under different load conditions, altogether 24 load cases, which are divided into 8 groups, are considered in this FEA model [4]. Among these groups, 4 groups of conventional explosive blast and 2 groups of nuclear blast are considered, whose maximal values are the designed loads. Furthermore, in order to understand the damage process of the doors, 2 groups of conventional blast are considered whose maximal values are larger than the designed ones. These load cases may be able to cover all the situations that the doors may meet. The time-intensity relationships of the load cases are shown in Fig. 3. For short, the conventional blast time-intensity curves are abbreviated as Conventional Curves, while the nuclear blast time-intensity curves are abbreviated as Nuclear Curves.

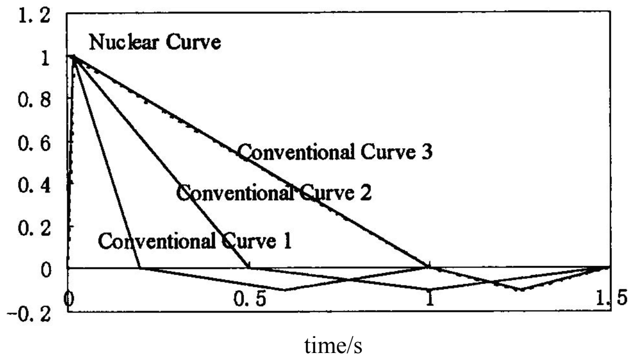

Fig. 3 Time-load relationships

Notice: It is assumed that the pressure of nuclear blast reaches maximal value immediately

(5) Integration time step: in order to set proper integration time step length, the free vibration frequency of the doors should be known. On one hand, the whole door leaf is just like a big simple supported slab that is supported on the doorframe. On the other hand, the steel plates on the door leaf are just like some small slabs fixed on the ribs. So the vibration models must be make up with three types of vibration: the global vibration of the whole door leaf, the local vibration of the steel plates, and the mixture of the former two types. Hence, more free vibration models are needed for the proper time step. The first 28 free vibration frequencies of the doors are between 0.002222s to 0.001186s. And there are 9 global vibration models appear in the first 28 models. So we can set the integration time step to be 1×10^{-6} s, which is much smaller than 0.001186s. And the computation should be stable and accurate.

(6) Element mesh: the elements are created by the automatic mesh function of ANSYS. The shell elements are meshed to be quadrangle and triangle elements. And the solid elements are meshed to be tetrahedron elements. In order to keep the numerical accuracy, the maximal size of shell elements is smaller than 7 cm, while the maximal size of solid elements is smaller than 5 cm.

4 Numerical results and discussion

4.1 Time-displacement curve of the door leaf center

Use door M1 as an example. The time-displacement curve of the door leaf center is shown in Fig. 4.

The following conclusions can be obtained from the figure.

1) The pressure-increase time for all conventional blast is set to be 16ms. It is much larger than the first free vibration period of the doors, which is just about 2.026ms. So the dynamic effect is not obviously. The maximal positive displacement of the door is close to the static one.
2) Because the pressure-increase time of the nuclear blast is assumed to be zero. So the dynamic effect is distinguished. The maximal positive displacement is obviously larger than the static one.

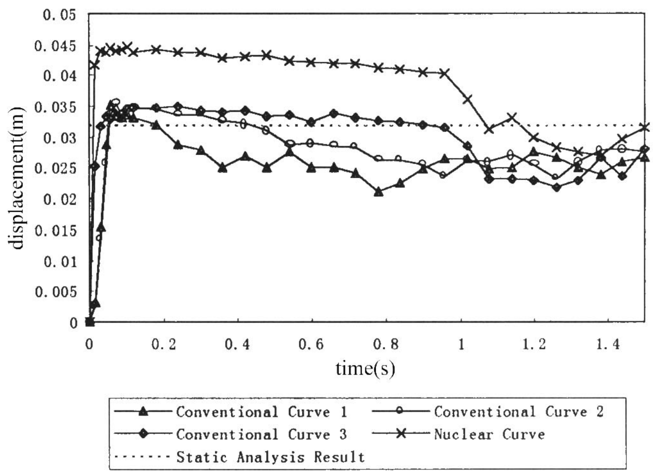

Fig. 4 Time-displacement curve of the door leaf center

3) In all load case, the door approaches to the maximal positive displacement at about 0.1s. Then the door leaf will be rebounded by the doorframe and door hinges. The more shortly of the positive pressure lasts, the rebound effect will be stronger. That is, the rebound effect of Conventional Curve 1 is the strongest.

4.2 The plastic deformation and the damage process

Still use the M1 door as the example. The distribution of plastic strain on the maximal positive displacement instant is shown in Fig. 5. It should be noticed that on this instant the door leaf is swelled to outside, but the hinges and the latches are clamped in the hinge bearings. So they cannot deform with the door leaf together and there is very large stress in them. This problem is not considered in the original design and it is a control state for the hinges and latches.

With the convenience of numerical simulation, we increase the maximal positive pressure step by step until the doors are destroyed. By this way, we obtained the damage process of the doors and their safety potential. The last damage process of the doors is shown in Fig. 6. The maximal positive pressure of the doors can bear are list as following: M0.5: 1000KPa; M1: 1500KPa; M4: 5000KPa

The following conclusion can be obtained from the plastic deformation and damage process of the doors:

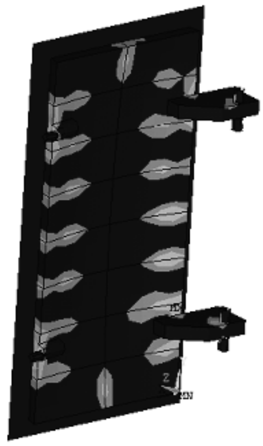

Fig. 5 Plastic strain distributions in the door leaf

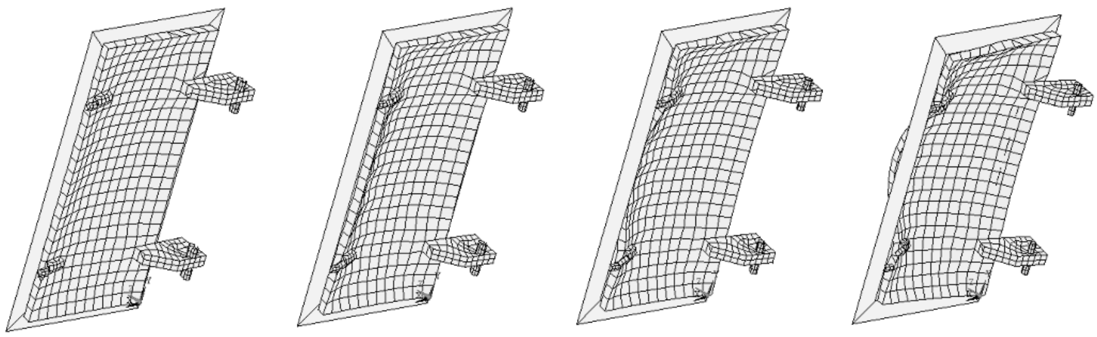

Fig. 6 Damage process

1) The damage process is: because there is too large deformation in the door leaf, its left and right sides slide out from the doorframe and thus cause the door fails.
2) Under the maximal designed blast load, there is some plastic strain in the doors, but the doors still are far away from the failure.
3) Because the blast-resist-door is a special type of structure, the blast belongs to the incidental load, and further more, the doors are designed that they just need to resist once blast, thus the safety margin should be lower. From the analysis above, we can see that even there is some relatively large plastic strain in the door leaf, there is still about 20%～100% safety margin in the door. Here the discrete degree of material is considered, too. So the traditional allowable stress design method, which is used widely in steel structure, is not suitable in this structure and it may be lead to uneconomical. And the ultimate state design method, which is based on test or FEA, is suitable for it.
4) Because the failure of the door is the door leaf slide out from left and right sides, the frame on the bottom is not important for the safety of the door. So the doorframe on the bottom can be omitted.

4.3 Compare between the conventional blast and nuclear blast

The Nuclear Curve is assumed that the pressure-increase time is zero, while the Conventional Curve 3 is assumed it to be 16ms. The other parameters of the two curves are the same. The result differences of the two curves, whose maximal positive pressure values are set to be the designed load, are list in the table 3.

From table 3 we can see that because the door M0.5 has relatively large safety margin (＞2.0), most of the door leaf is in the elastic state under design load. So the two load cases have no obviously difference. However, for M4, its safety margin is only 1.2～1.3, and a lot of steel plates in the door leaf go to plastic state under the designed load. Hence, there is obviously difference between the nuclear blast and conventional blast.

Table 3 Compare of nuclear blast and conventional blast

	M 0.5	M 1	M 4
Maximal displacement of nuclear blast (/mm)	26.1	35.1	59.8
Maximal displacement of conventional blast (/mm)	27.3	44.9	80.2
Ratio (nuclear/conventional)	1.05	1.28	1.34
Safety margin of the door	2.0	1.5	1.2

4.4 Rebound effect factor

After the positive blast pressure, on one hand, a negative pressure will be applied on the door leaf. On the other hand, the door leaf will rebound because of the impact between the door leaf and the doorframe. Both of these forces will be resist by the door hinges and door latches. And these forces are important parameter for the hinges and latches. The value and the distribution of the rebound force are difficult to obtain for the static method. But in this analysis, with the contact function of LS-DYNA, the contact between the door leaf and the doorframe, and the contact between the door hinges and the door bearings, can be simulated and the rebound force can be calculated, which is listed in table 4.

Table 4 Rebound Force

	M 0.5	M 1	M 4
Total Rebound Force (/kN)	801	1492	4739
Maximal Positive Force (/kN)	1097	2194	8776
Equivalent Negative Pressure Factor*	0.73	0.68	0.54

*Equivalent Negative Pressure Factor=Total Rebound Force/Maximal Positive Force

In the USSR code for blast resist structure, the rebound factor is 0.7, while the rebound factor in USA code is 0.5. From table 4, it can be seen that because the door M0.5 has relatively large safety margin, the whole door is in the elastic stage. So the rebound effect is very strong. And the foreign code maybe unsafe for this door. However, since M4 has large plastic deformation and lots of energy is absorbed in the plastic deformation, the rebound effect is relatively slight and the foreign code may cause too large safety margin.

5 Conclusions

1) Dynamic FEA for a series of blast-resist-doors is presented in this paper. The computation successfully simulated the deformation and damage process of the doors. Many important results are obtained which are difficult for the static analysis.
2) For such special structure as blast-resist-doors, in order to ensure the safety and rationality of the design, it had better use the ultimate design method, which is base on test or FEA. And the safety factor should be estimated after the damage process is known.
3) The contacts between the door leaf and doorframe, as well as the door hinges and the door hinge bearings, are important to the safety of the doors. So the contact effect should be considered carefully in FEA model.
4) Because the blast effect is indeterminate, more blast load cases should be considered in the safety analysis to

ensure the result is correct and all sidely.

References

1 Manual for ANSYS. Beijing Agency of ANSYS Company, 1999

2 LS-DYNA Structural User's Manual. Livermore Software Technology Corp.1999

3 Chen Zhaoyuan. Behavior of RC structure under impact load. Beijing: Tsinghua University Press, 1986

4 Li Yiqi. Blast mechanics. Beijing: China Science Press, 1992

5 Guo Zhenhai. Principle of reinforced concrete. Beijing: Tsinghua University Press, 1999

6 Wang Guoqiang. Practical numerical simulation technology and application on ANSYS. Xi’an: Northwest Industry University Press, 2000

7 Wang Guozhou, Qu Luqian. Steel structure—principle and design. Beijing: Tsinghua University Press, 1993