Project Code : 240601

STRUCTURAL DESIGN AND ANALYSIS

Auto / Manual Double Blast Proof Door

2004. 6.

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SAM HOON MACHINERY COMPANY

KOREAN PROFESSIONAL ENGINEERS ASSOCIATION

DONG YANG CONSULTING ENGINEERS Co., Ltd.

- STRUCTURAL DESIGN
- CONCEPT STUDIES
- SEISMIC ANALYSIS
- SPECIAL STRUCTURE DESIGN
- CONSTRUCTION METHOD CONSULTING & DESIGN
- PROJECT MANAGEMENT

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Project Code : 240601

DESING REPORT FOR BLAST DOORS

Auto / Manual Double Blast Proof Door

Attendance of Report Preparation

Se/Pe of Structural Engineering, Hyo Jin, Kim

M.E of Structural Engineering, Il Won, Mun

M.E of Structural Engineering, Jin Hee, Lee

Date : June, 10^{th} 2004

DONG YANG CONSULTING ENGINEERS Co., Ltd.

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ABSTRACT

SUPPLY : SAMHOON MACHINERY COMPANY

PROJECT CODE : DYCE-240601

SUBJECT : Auto / Manual Double Blast Proof Door

Contents:

This project presents the result for checking of the structural stability of a blast door under explosion loading. In this report, a detailed 3-dimensional analytical model of the subject structure was constructed using the SAP 2000, a finite element program widely used in performing linear and nonlinear behaviour of structures around the world. In particular, a 3D model was created discretizing all structural components into finite elements to simulate as accurately as possible the realistic behaviour of the structure when subjected to explosion loading.

This project was conducted by the request from SAMHOON MACHINERY COMPANY. The subject was the Auto / Manual Double Blast Proof Door, which was going to be constructed in Indonesia. The main purpose of this project was to check the structural stability of the blast proof door when subjected to the maximum allowable explosion loading. Based on the structural analysis with SAP 2000, it was concluded that the structure was stable enough to resist explosion loading. Also it was considered that the structure consisting of thick steel plates along with the Rib system was well designed to withstand explosion loading, providing an excellent structural stability.

Period of Research : June 3, 2004 ~ June 10, 2004

Attendance of Report Preparation :

Double Blast Proof Door Design : Samhoon Machinery Company
Structural Design : Dong Yang Consulting Engineers Co., Ltd

Structural Designer
Se/Pe, M.E of Structural Engineering, Hyo Jin, Kim

M.E of Structural Engineering, Il Won, Mun

M.E of Structural Engineering, Jin Hee, Lee

June 10, 2004

Dong Yang Consulting Engineers Co., Ltd

BLAST DOOR SCHEDULE

2004-06-10

- SUPPLY : SAM HOON MACHNERY COMPANY
- CUSTOMER : AIREF ENGINEERS (P)LTD.
- STRENGTH CALCULATIONS : DONGYANG CONSULTING ENGINEERS CO., LTD.

Door Type	Location	Description	Specification	Q'TY	Remark
Manual Swing Type		900(w)x2000(h)x600	25Bar	6EA	Sing Type
Auto/Manual Swing Type		4,000(w)x4,000(h)x600	25Bar	6EA	Double Type
Auto/Manual Swing Type		2,500(w)x2,000(h)x600	25Bar	2EA	Double Type
Auto/Manual Swing Type		4,000(w)x3,000(h)x600	25Bar	1EA	Double Type

Note.

In verifying the efficiency of blast proof for the 25Bar Blast Door, the door 4,000(w)×4,000(h)×600 size, which was designed to resist the maximum allowable blast pressure, was inspected. Therefore, it confirms that the rest of blast doors meet with the required efficiency of blast proof.

1. Design Criteria

Structural stability check of Auto/Manual Double Blast Proof Door

■ Design Method & Criteria

	Contents	Ref.
Design Code	Steel : Allowable Stress Method	
Reference Code	Korean Building By-Low AISC 9th Code (1989)	

■ Strength of Structural Materials

Structural Member	Material	Design Strength $F_y (kg/cm^2)$		규격번호	Ref.
		t ≤ 40mm	t > 40mm		
Plate	A36 (SS400)	2,400	2,200	KS D 3515	ASTM A36
	SM400B	2,400	2,000	KS D 3515	ASTM A36
Welding	E43			KS D 7004	
Latch Pin	SM45C			KS D 3698	

■ Dimension of the Double Blast Proof Door

• 4,297(width) × 4,200 (Height), (unit: *mm*)

■ Blast Pressure applied to the Double Blast Proof Door

• 25 Bar = 25 × 1.02 kg/cm^2 = 25.5 kg/cm^2

■ Check Item

• Structural stability check for a Double blast proof door
• Structural stability check for a Double blast proof door Frame

■ Program used for the Structural Analysis

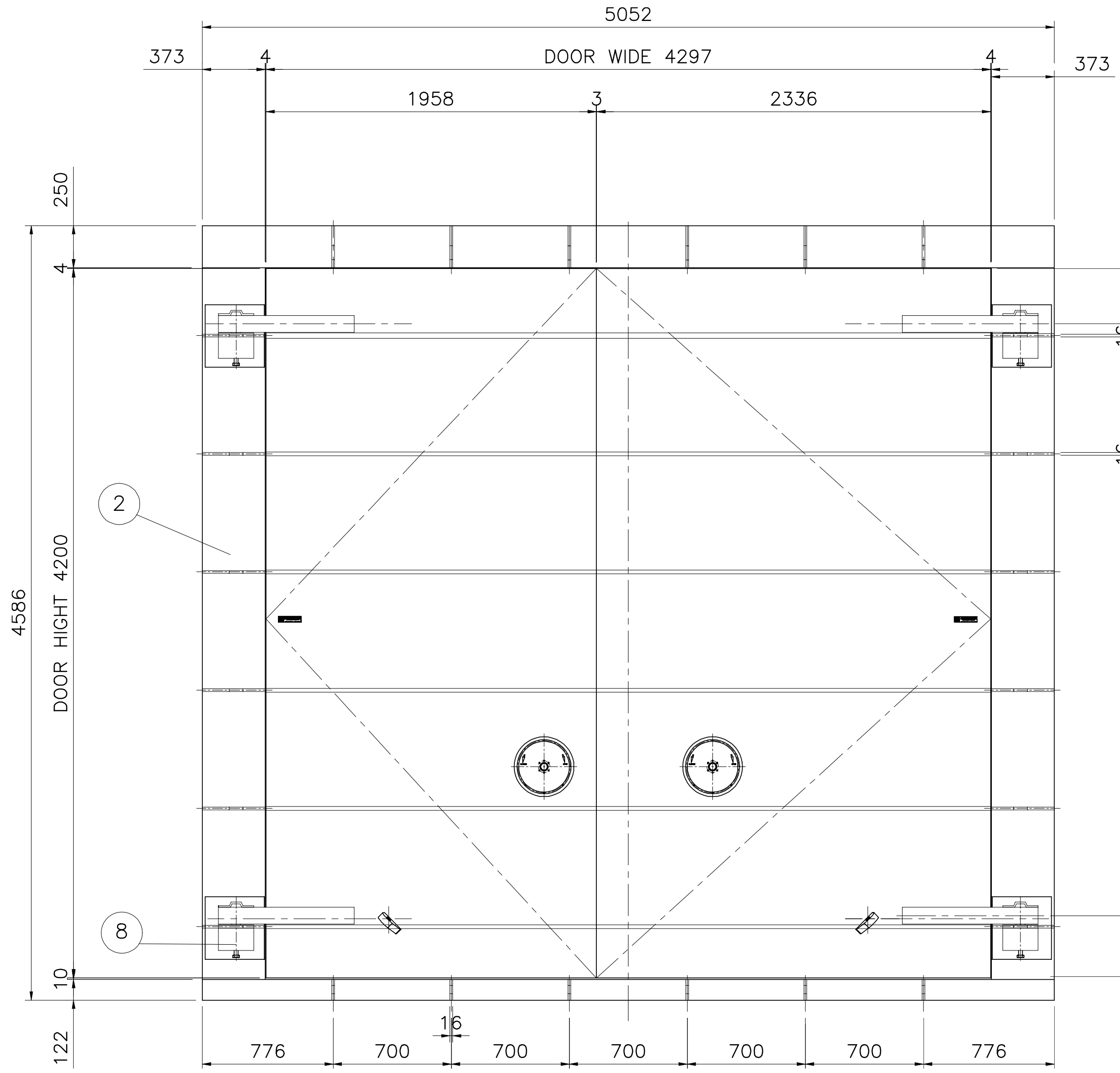
• SAP 2000

Sap2000 Analysis Features

The Sap2000 Structural analysis program has the following features

- Static and dynamic analysis
- Linear and Nonlinear analysis including seismic analysis
- Vehicle live-load analysis for bridges
- P-Delta analysis
- Frame and shell structural elements, including beam-column, truss, membrane
- Two- and three-dimensional and axisymmetric solid elements
- Nonlinear link and spring elements
- Multiple coordinate systems
- Many types of constraints
- A wide variety of loading options
- Alpha-numeric labels
- Large Capacity
- Highly efficient and stable solution algorithm

2. Framming Plan



3. Model Analysis

3.1 Finite Element Model

A 3-dimensional analytical model of a double blast proof door was constructed using SAP 2000 for a structural analysis. A finite element model for a double blast proof door designed by Samhoon Machinery Company was created with shell structural elements. To simulate as accurately as possible the realistic behaviour of the structure when subjected to explosion loading, all structural components was discretized into small shell elements using Mesh. Finite element analyses were then mainly performed for steel plate and rib members consisting of the double blast proof door, which were designed to resist explosion loading primarily. In addition, a Door Frame supporting the blast door and Pins connecting between the door and the door frame were modelled as well. These elements are presented in detail as follow.

■ The section properties of the Door Frame

Horizontal steel plate	16.0 t
Vertical steel plate	22.0 t
Welding Stud Bolt	M16 × 300L

■ The section properties of the Double Blast Proof Frame

Outer vertical steel plate	30.0 t
Inner horizontal Rib	32.0, 22.0 t
Latch Pin	Φ 50mm
Rear Cover Steel Plate	9.0 t
Inspection Cover Steel Plate	9.0 t

■ Description of the Double Blast Door

Auto/Manual Double Blast Proof Door consisted of outer vertical plates with 30 mm thick and inner horizontal Ribs with 32 and 22 mm thick. The horizontal Ribs were welded on outer plates with 700 mm spacing. This double system door was designed to withstand explosion loading. The door frame supporting the blast door was embedded in concrete wall, using stud bolt.

In carrying out the structural analysis for this kind of structure supported by the door frame, the main issue was how to apply the boundary condition on the model. The boundary condition is important factor in structural analysis as it would induce not only unwanted errors in the structural analysis processing but also discrepancies in the result. Therefore, in this project the boundary condition was chosen as closely as possible to the given structure condition.

Figures 3.1~ 3.4 display the 3D FE model of the subject structure. The blast proof door with outer vertical steel plates and inner horizontal ribs and the door frame around door were modelled with the shell element. Pins around the door frame modelled with the solid element is shown in Figure 3.5. In this FE model, the total created nodes and shell elements were 22656, 23156 respectively.

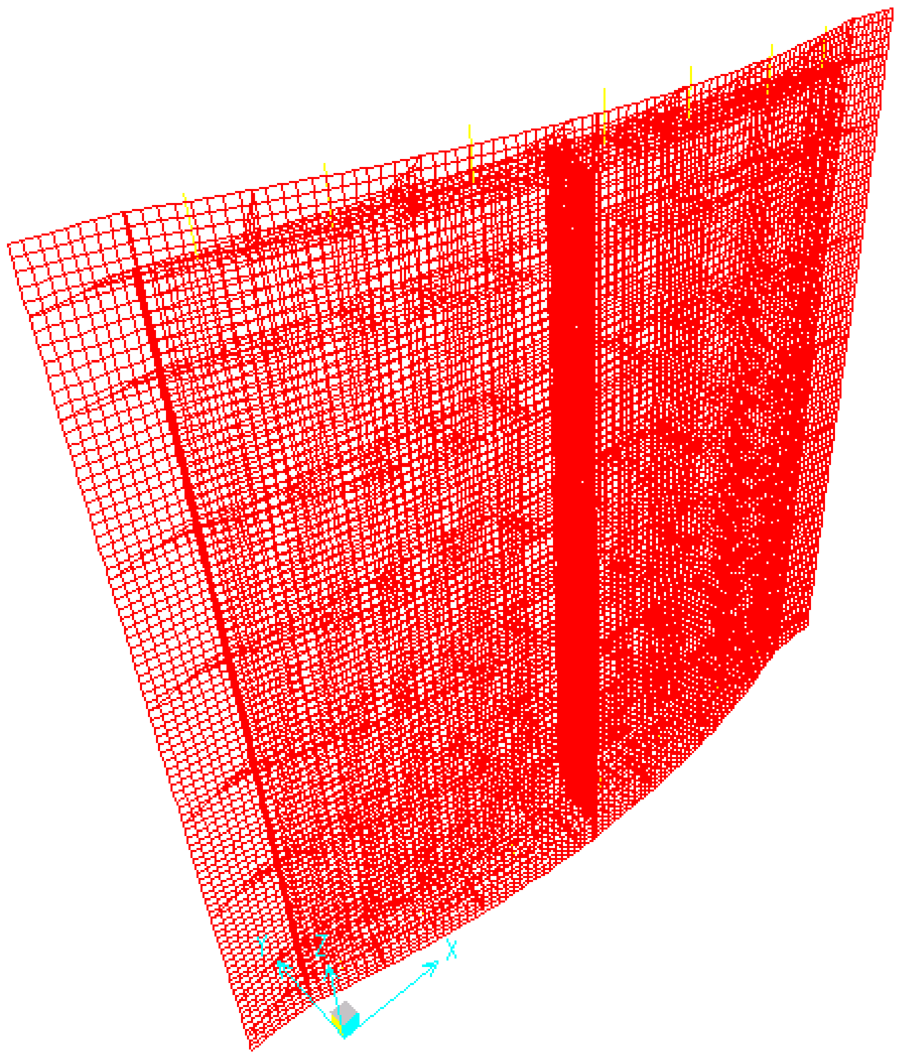


Fig 3.1 The front view of the entire finite element model of the Double Blast Proof Door system

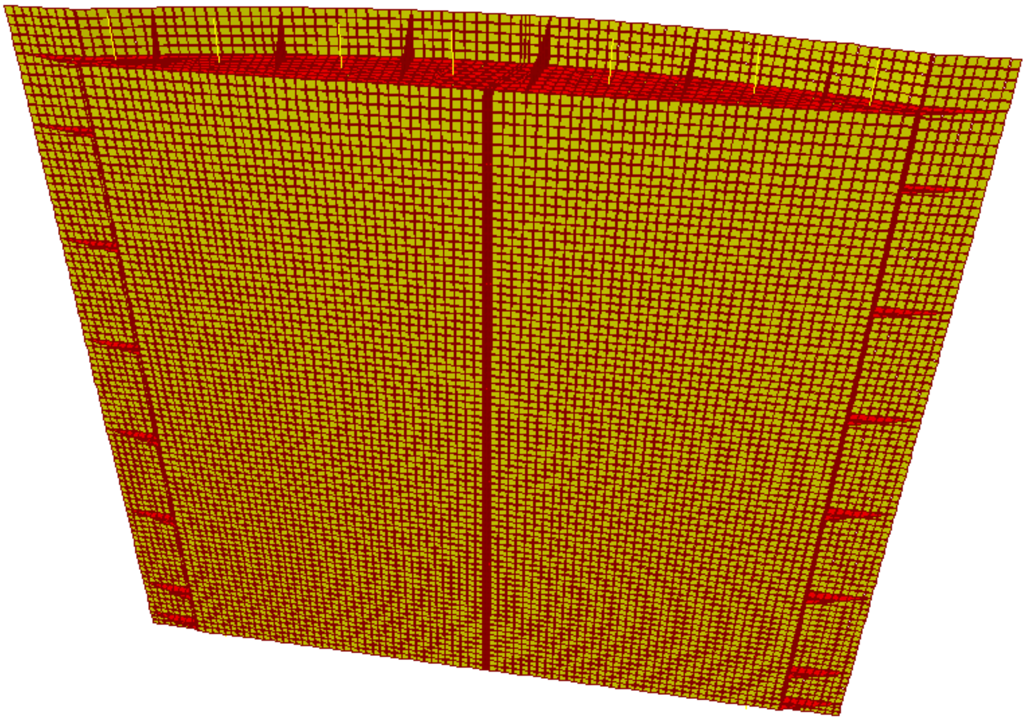


Fig 3.2 The rear view of the entire finite element model of the Double Blast Proof Door system

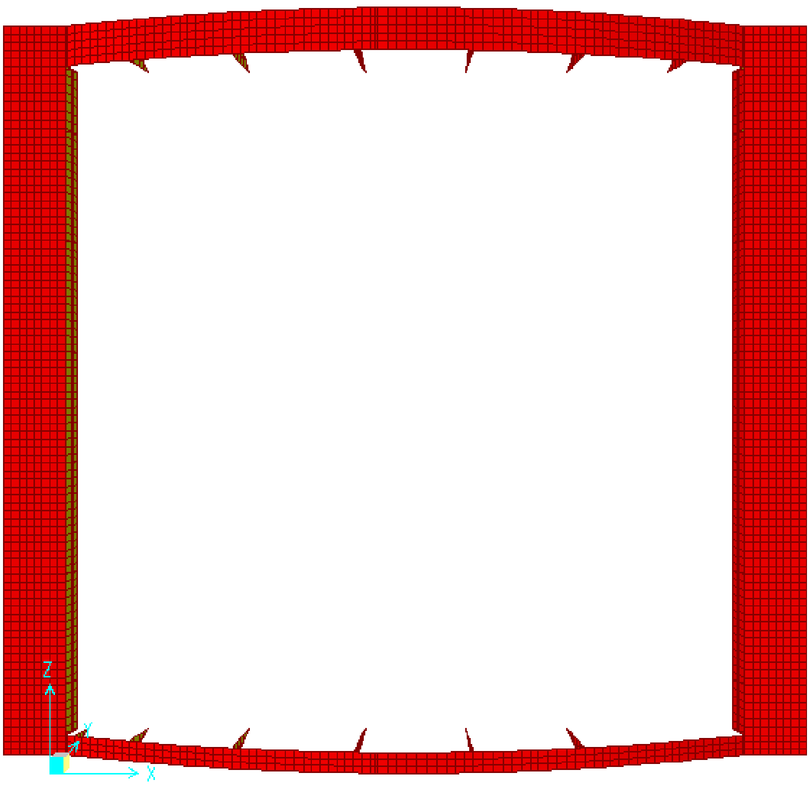


Fig 3.3 The finite element model of the Door Frame

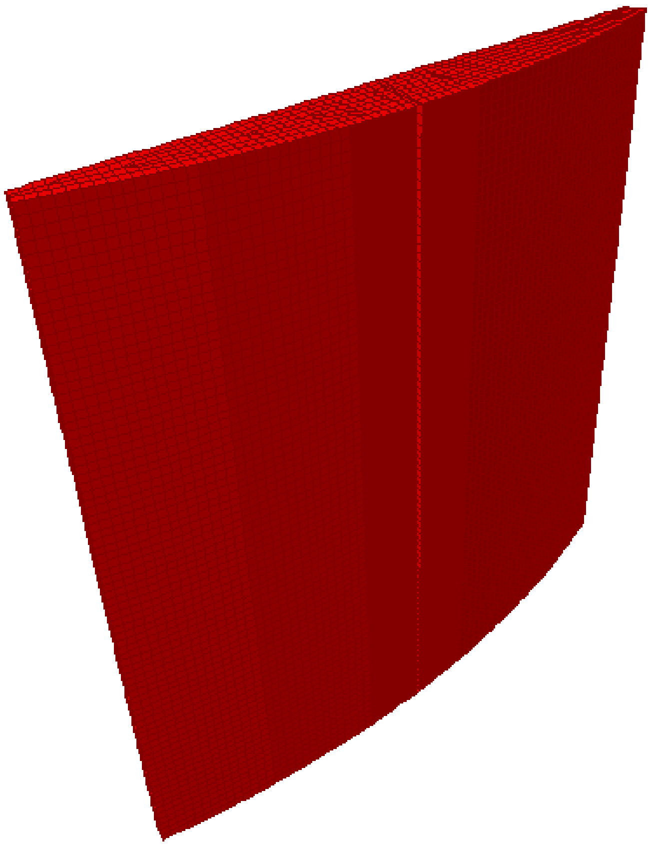


Fig 3.4 The finite element model of the Double Blast Proof Door

Fig 3.5 The finite element model of Double Blast Proof Pins

3.2 Loading & Design Condition

The maximum allowable explosion loading applied to the outer vertical steel plate was blasting Pressure 25Bar. This 25Bar value was the uniform load corresponding to the door height and is converted to 25.5kg/cm^2 pressure. This conversion pressure loading applied to the outer steel plate is shown in Figure 3.6

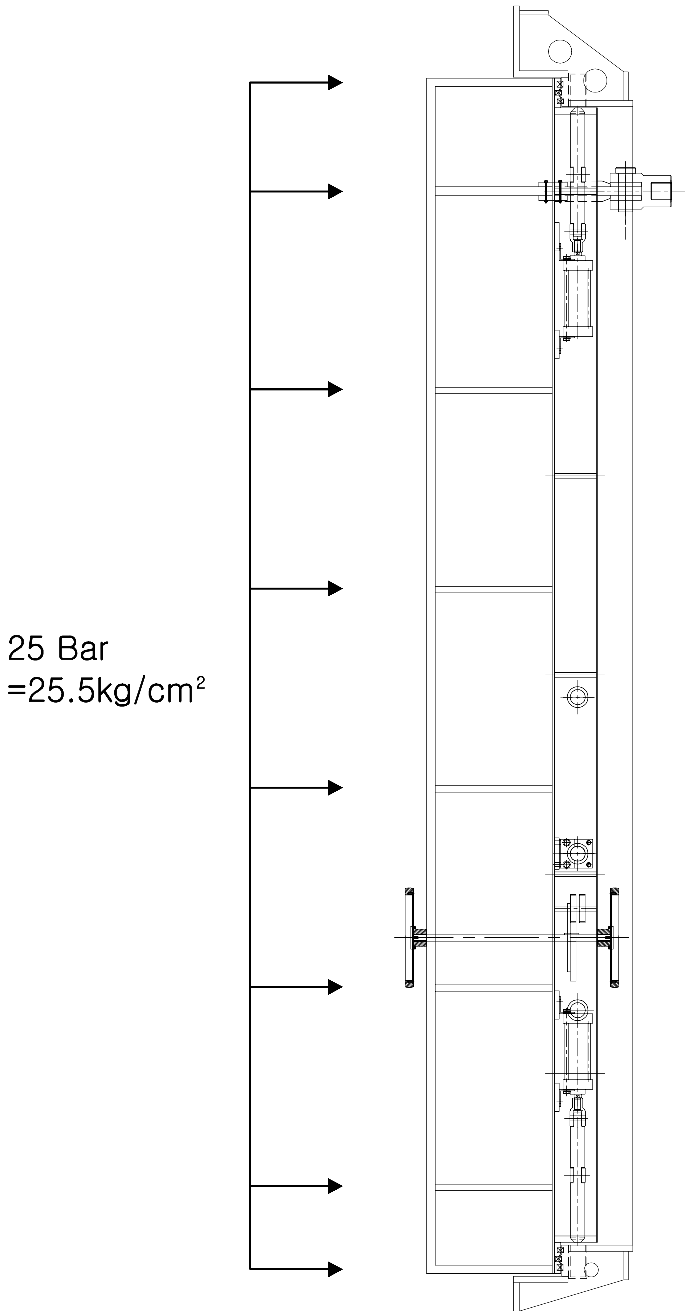


Fig 3.6 The applied force to Double Blast Proof Door

The material properties used were A36 (SS400), SM400B and SM45C for the door finish, door frame, and door pin respectively. The subject structure was under influence of bending and shear stress. The material property of steel used is given in Tables 3.1 and 3.2

Table 3.1 The allowable bending stress of steel, kgf/cm^2 (KBC)

Plate Thk	A36 (SS 400) SM 400B	SM 490	SM 490Y SM 520
Less than 40	1.600	2,200	2,400
More than 40	1,400	2,000	2,200

Table 3.2 The allowable shear stress, kgf/cm^2 (KBC)

Plate Thk	A36 (SS 400) SM 400B	SM 490	SM 490Y SM 520
Less than 40	923	1,231	1,385
More than 40	846	1,154	1,270

- SM45C (A36(SS400) < SM45C < SM490)

4. Structural Analysis Ouput

In the structural analysis conducted on the subject structure, the stability of structural members were evaluated based on Allowable Stress Design method. Figure 4.1 presents the computed displacement diagram for the blast proof door subjected to explosion loading. It was examined whether the deflection due to the deformation would cause any problem for the structural safety.

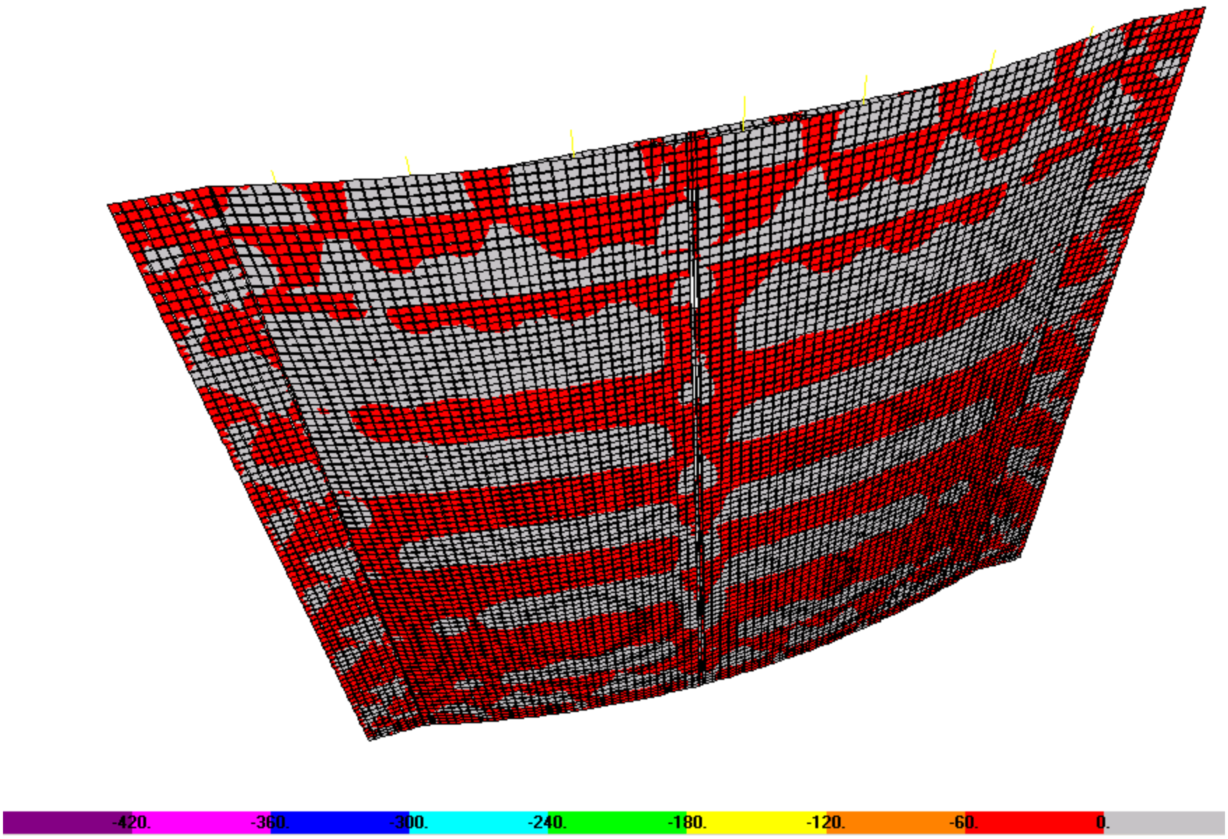


Fig 4.1 Bending Moment Diagram of Blast Proof Door

As mentioned earlier, all structural members consisting of the Double Blast Proof Door system were modelled with shell elements. The maximum bending stress and shear stress for the shell element were calculated by Equation 4.1

Bending stress : $\sigma_x = -\frac{12M_x y}{t^3}$, $\sigma_y = -\frac{12M_y y}{t^3}$, $\sigma_{xy} = -\frac{12M_{xy} z}{t^3}$ (4.1)

Here, *t* is the thickness of the plate and $z = \frac{t^2}{6}$, $I = \frac{t^3}{12}$

In addition, Pins connecting the blast proof door and frame were modelled with solid elements with 30 mm diameter, which were then discretized into small meshes. The maximum stress of the Pin, $\tau_{\max}$ was computed by Equation 4.2.

$$\tau_{\max} = \frac{4V}{3A} \tag{4.2}$$

4.1 Calculation the bending and shear stress of members

4.1.1 Outer vertical steel plate of the Double Blast Proof Door

The used thickness of the outer vertical steel plate model was 30 mm thick. Explosion loading was applied to the outer vertical steel plate and the finite element analysis was then performed. From the result of the FE analysis, the maximum stresses were observed near the door hinge. Figure 4.2 displays the bending moment diagram of the double blast proof door. The bending and shear stress acting on steel plates were checked over their thickness and these results are as follows :

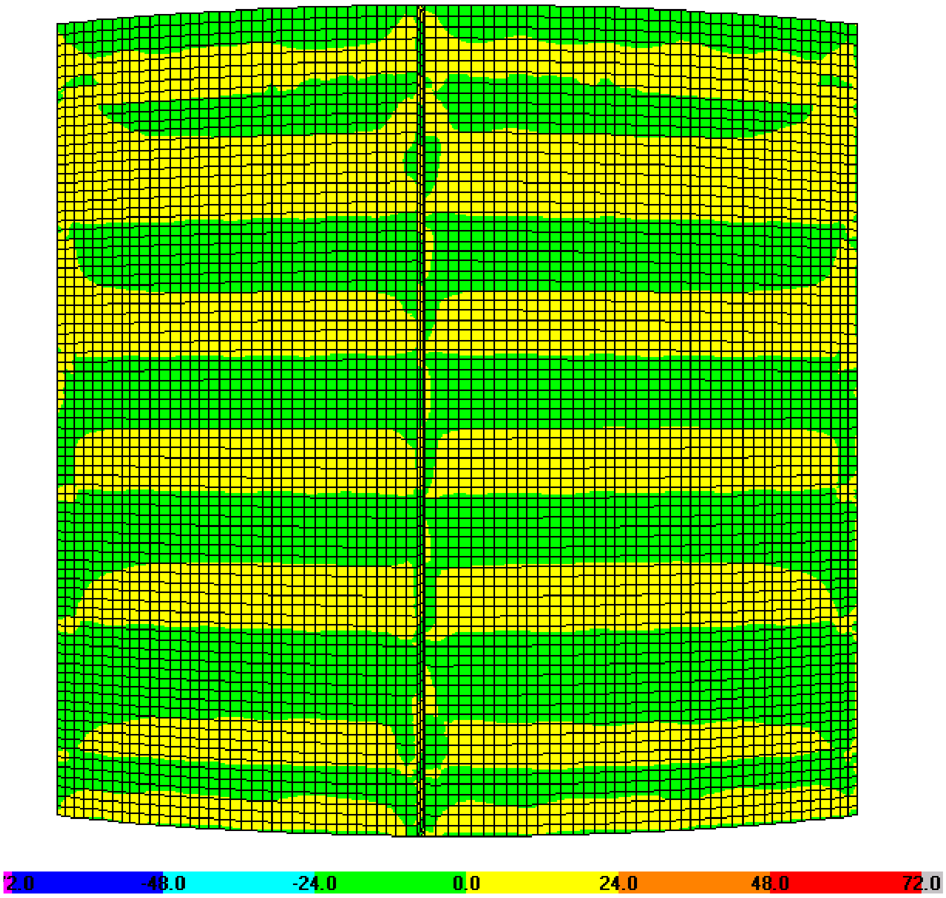


Fig 4.2 The Bending Moment Diagram of Vertical Steel Plates, M22

■ Bending Stress Check

$$\sigma_x = \frac{12M_x z}{t^3} = \frac{12\times327\times1.5}{3^3} = 218 \ kgf/cm^2$$

∴ Maximum Bending Stress ($218\ kgf/cm^2$) < Allowable Bending Stress ($1,600\ kgf/cm^2$)

$$\sigma_y = \frac{12 M_y z}{t^3} = \frac{12 \times 375 \times 1.5}{3^3} = 250\ kgf/cm^2$$

∴ Maximum Bending Stress ($250\ kgf/cm^2$) < Allowable Bending Stress ($1,600\ kgf/cm^2$)

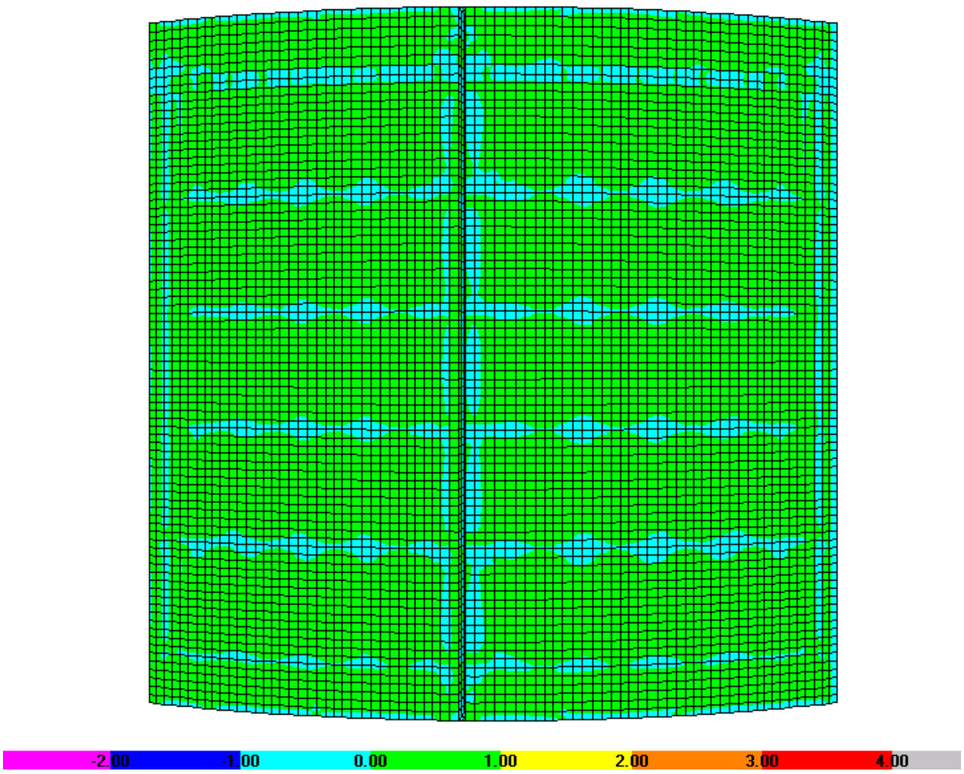


Fig 4.3 The Shear Force Diagram of Vertical Steel Plates, V23

■ Shear Stress Check

$$\tau_{xy} = \frac{12 M_{xy} z}{t^3} = \frac{12 \times 75.7 \times 1.5}{3^3} = 50.47\ kgf/cm^2$$

∴ Maximum Shear Stress ($50.47\ kgf/cm^2$) < Allowable Shear Stress ($927\ kgf/cm^2$)

From the above results, it was revealed that the bending and shear stress acting on the blast proof door under explosion loading was within the range of allowable stresses. Therefore it was considered that the double blast proof door was structurally safe enough to withstand the explosion loading.

4.1.2 Door Frame

The door frame consisted of horizontal steel plates with 16 mm thick and vertical steel plates with 22 mm thick. From the FE analysis, the maximum stresses were found near the connecting part of the blast proof door and the door frame. This was attributed to the stress concentration occurring on inner horizontal Ribs. The bending and shear stress acting on steel plates were checked over their thickness and these results are as follows:

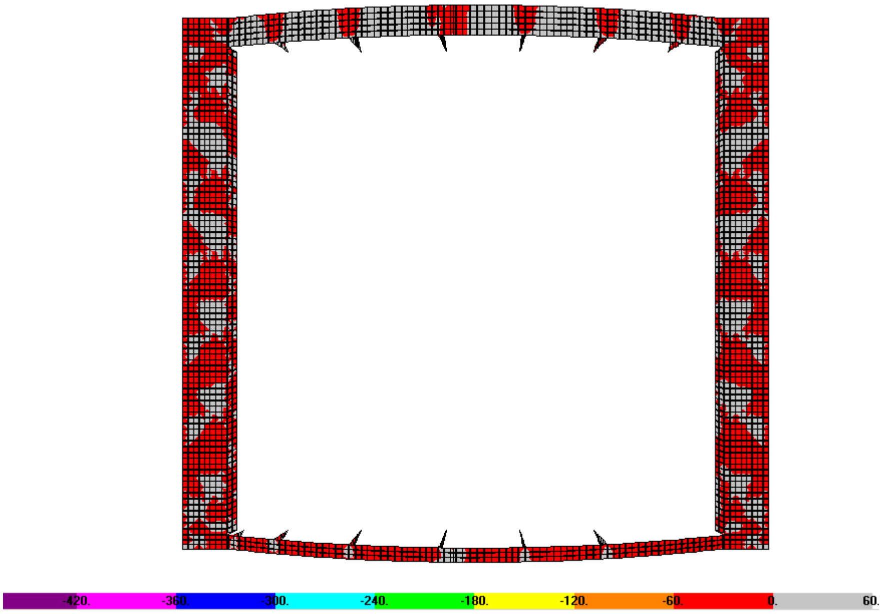


Fig 4.4 The Bending Moment Diagram of the Door Frame, M11

- Bending Stress Check

$$\sigma_x = -\frac{12M_x z}{t^3} = -\frac{12\times2.075\times7.25}{1.6^3} = 44.07\ kgf/cm^2$$

∴ Maximum Bending Stress($44.07\ kgf/cm^2$) < Allowable Bending Stress ($1,600\ kgf/cm^2$)

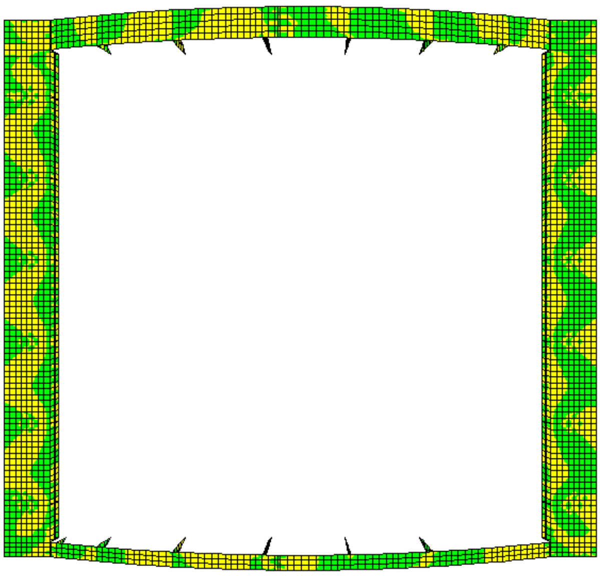


Fig 4.5 The Bending Moment Diagram of the Door Frame, M11

- Shear Stress Check

$$\tau_{xy} = -\frac{12M_{xy} z}{t^3} = -\frac{12\times5.1\times7.25}{1.6^3} = 108.3\ kgf/cm^2$$

∴ Maximun Shear Stress ($108.3\ kgf/cm^2$) < Allowable Shear Stress ($927\ kgf/cm^2$)

From the above results, it was revealed that the bending and shear stress acting on the door frame under explosion loading was within the range of allowable stresses. Therefore, it was considered that the door frame was structurally safe.

4.1.3 Inner Horizontal Rib

The steel plate thicknesses of horizontal Ribs consisting of the double blast proof door were 32 mm and 22 mm. From the FE analysis, it was revealed that the stress was concentrated on the horizontal Ribs. This phenomenon indicates that the Blast proof door is supported by the horizontal Rib system when subjected to explosion loading. The stress acting on Ribs were checked for the direction of the element local 3 axis.

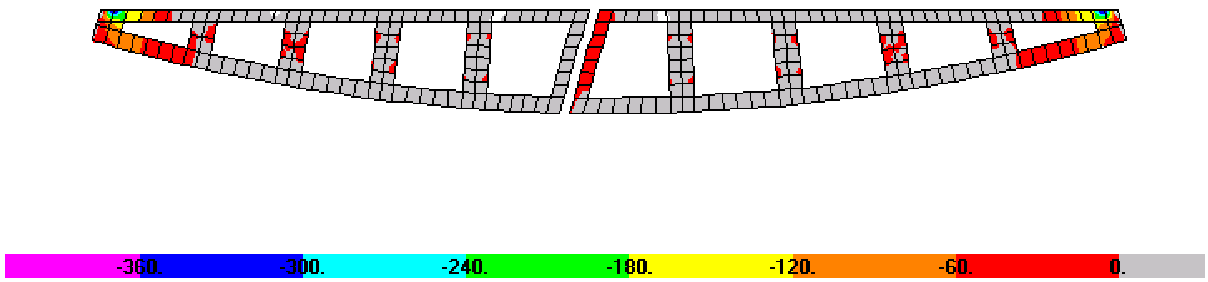


Fig 4.6 The Bending Moment Diagram of the Horizontal Rib Plate, M11

- Bending Stress Check

$$\sigma_x = \frac{12M_x z}{t^3} = \frac{12\times 100.2\times 45}{3.2^3} = 89.9\ kgf/cm^2$$

∴ Maximum Bending Stress($115.9\ kgf/cm^2$) < Allowable Bending Stress ($1,600\ kgf/cm^2$)

$$\sigma_y = \frac{12M_y z}{t^3} = \frac{12\times 126.6\times 2.5}{3.2^3} = 115.9\ kgf/cm^2$$

∴ Maximum Bending Stress($115.9\ kgf/cm^2$) < Allowable Bending Stress ($1,600\ kgf/cm^2$)

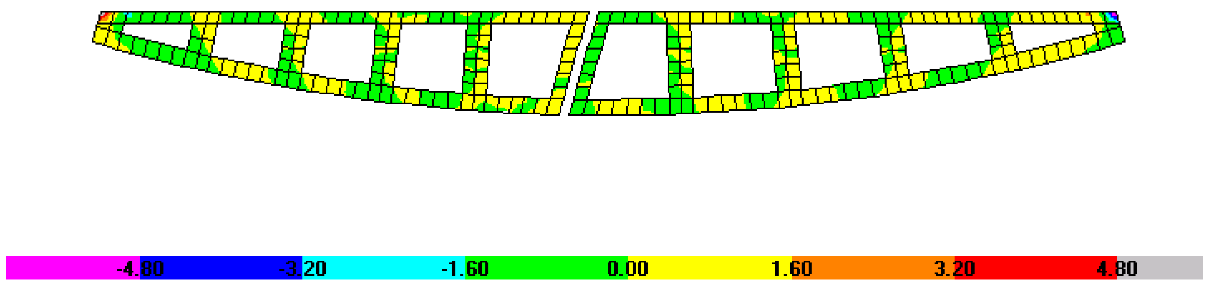


Fig 4.7 The Shear Force Diagram of the Horizontal Rib Plate, V13

- Shear Stress Check

$$\tau_{xy} = \frac{12M_{xy} z}{t^3} = \frac{12\times 163.6\times 3.15}{3.2^3} = 188.72\ kgf/cm^2$$

∴ Maximun Shear Stress ($188.72\ kgf/cm^2$) < Allowable Shear Stress ($927\ kgf/cm^2$)

From the above results, it was concluded that the bending and shear stress acting on the horizontal Rib under explosion loading was within the range of allowable stresses. Therefore, it was considered that the horizontal Rib was structurally safe.

4.1.4 Latch Pin

Fig 4.8 The bending Diagram of Latch Pin, M22

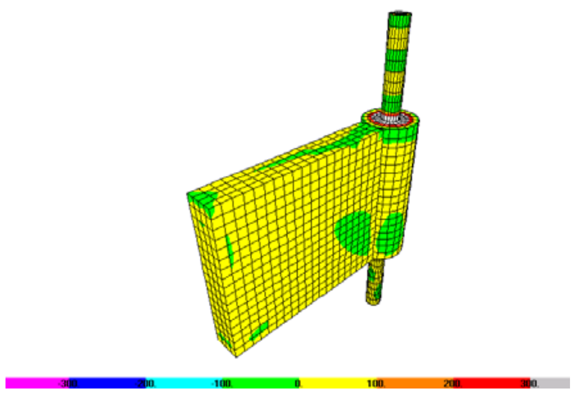


Fig 4.9 Door Pin Bending Moment Diagram, M11

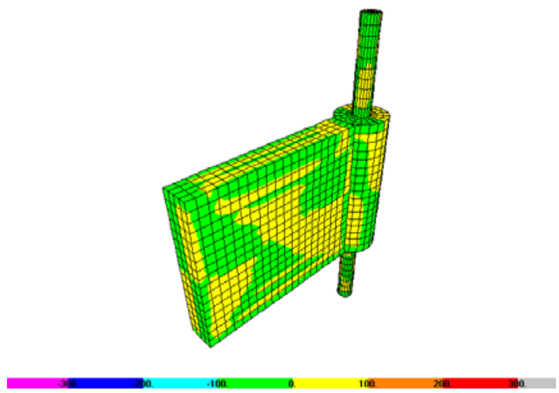


Fig 4.10 Door Pin Shear Diagram, V13

Based on the stress checking, it was found that the stress occurring on Latch Pin and Door Pin was negligible, almost zero. In consequence, it was considered that the Latch Pin was structurally safe enough.

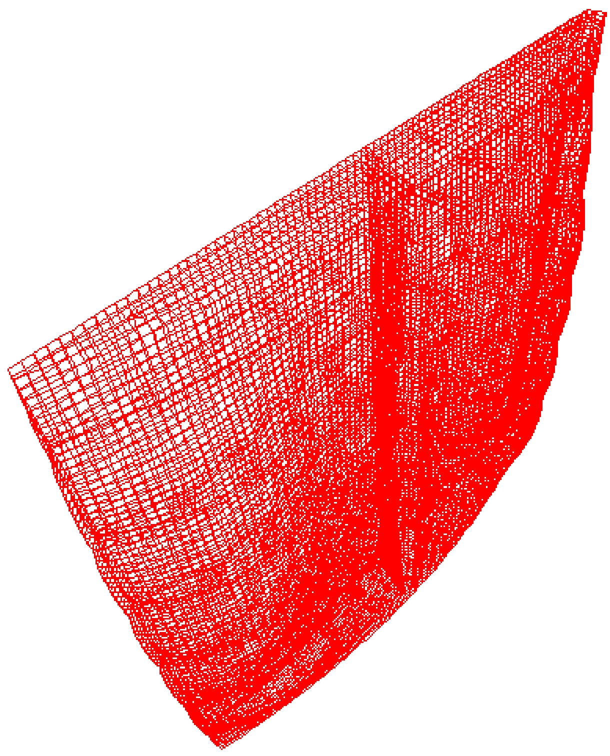


Fig 4.11 The Deformation of the double Blast Door

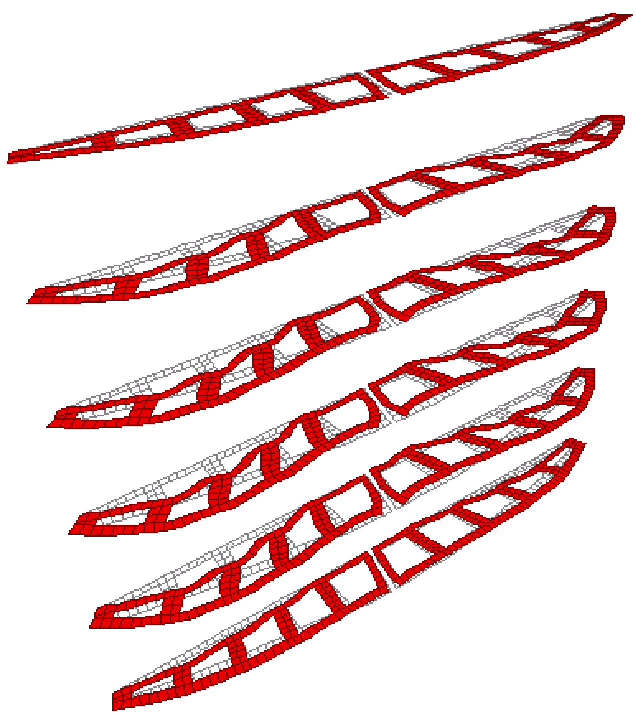


Fig 4.12 The Deformation of Rib Plates

Table 4.1 presents the comparison the stress value calculated from the FE analysis with the allowable stress based on the ASD code. As shown in Table 4.1, it was considered that all members consisting of the double blast proof door system were structurally safe enough under explosion loading.

Table 4.1 Allowable Stress Comparison

Member	Allowable Stress	Stress value of member	Remark
Frame Plate	Allowable Bending Stress ($1,600\ kgf/cm^2$)	250	O.K
	Allowable Shear Stress ($927\ kgf/cm^2$)	50.47	
Door Plate	Allowable Bending Stress ($1,600\ kgf/cm^2$)	44.07	
	Allowable Shear Stress ($927\ kgf/cm^2$)	108.3	
Latch Pin	Allowable Bending Stress ($1,600\ kgf/cm^2$)	115.9	
	Allowable Shear Stress ($927\ kgf/cm^2$)	188.72	

5. Conclusion

The Finite Element analyses were performed on the Auto/Manual Double Blast Proof Door designed by Samhoon Machinery Company with SAP 2000 in order to check its structural stability when subjected to explosion loading. The output stresses generated from the FE analyses were checked by the Allowable stress design method. The following conclusion were based on the FE analysis result reported in the previous chapter.

The Blast Proof Door when subjected explosion loading showed its enough structural stability under the maximum allowable blast pressure 25 Bar. In particular, it was found that the outer vertical steel plate and the horizontal Rib system consisting of the blast proof door was strong enough to withstand explosion loading. Therefore, it was considered that the thickness of steel plate used for the Blast Proof Door was appropriate for the design load. Also the stress acting on the door frame and Pin was found to be within the range of the allowable stress, giving enough insurance for their structural stability .