ULTIMATE STRENGTH ANALYSIS OF BOX GIRDER UNDER HOGGONG BENDING MOMENT, TORQUE AND WATER PRESSURE

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Abstract

In this paper, the ultimate strength analysis of the box girders under combined load is investigated using a commercial FEA program, ABAQUS. It studies the ultimate strength analysis of the Reckling No. 23 box girders model. This paper mainly analyzes the influence of the ultimate strength of the box girders model under hogging bending moment, torque moment and water pressure simultaneously. In next step, laying a foundation for accounting the ultimate strength of the actual ship model

Keywords: *Ultimate strength, nonlinear finite element, box girders*

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1. INTRODCUTION

Thin-wall box girders are a typical construction of spatial shell beam. As it features with light weight, strong strength and other advantages, the thin-wall box beam is widely used in the ship shaped offshore structures, bridge girder, building etc. Many researches on structural mechanics have attached a great importance to the ultimate strength of the box girders. In this paper, ultimate strength of box gider under hogging bending moment, torque moment and water pressure simultaneously in a oil ship model are calculated by FEA program, ABAQUS. It aims to explore the influence on the ultimate strength of box girder under combined load

2. NONLINEAR FINITE ELEMENT ANALYSIS OF THE BOX GIRDER

2.1 Geometric and Material Properties.

The present paper uses Reckling No. 23 box girder model to study finite element method for ultimate strength analysis of box girder [i]. Length of stiffener: L = 500mm; breadth of box girder B=600mm; height of box girder H=400mm. The dimension and material properties of model are shown in Fig.1 and Table 1.

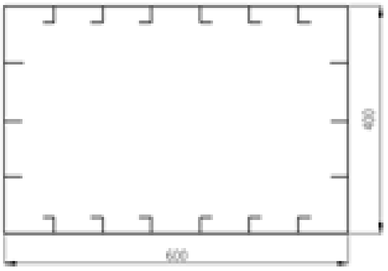


Fig-1: Reckling No. 23 box girder

Table -1: Dimensions and material properties of the model

Stiffened Plate	**Dimension (mm)**	**σ_y(MPa)**	**E(MPa)**
Top plate	t_p=2.5	246	210000
Bottom plate	t_p=2.5	246	210000
Sides shell	t_p=2.5	246	210000
Flange of Stiffener	30.0×20.0×2.5	246	210000
Side of stiffener	30.0×2.5	246	210000

2.2. Finite Element Model

The research object has the section long of 500mm . The middle section of 500mm in three-span model of 1+ 1+1 is taken as the study object (as in Fig. 2).

In this paper, S4R shell element in ABAQUS has are used for plates and stiffener of box girder. Fig.2 shows the finite element model of the box girder model.

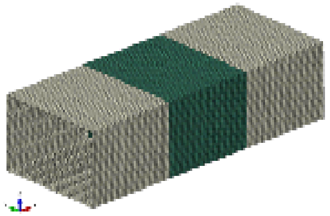


Fig- 2: Finite element

2.3 Loads and Boundary Conditions

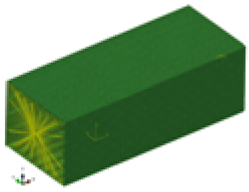
Multi-point constraint way is applied as it can effectively imitate the boundary conditions of the structure. Multi-point constraint way means controlling the displacement of slave node by identifying the displacement of master node, by which all the slave nodes will have the same displacement.

Here the reference master node is setting in the center of the two side facings of the box girder, the slave node being the points of the outside side facings.

In this way, the displacement increment of all the slave nodes in section facing is controlled by controlling the displacement increment of masternodes, and then the ultimate strength bending moment of box girder is accounted out, as shown in Fig 3

The master points at left ending can fully constraint Ux, Uy, Uz, and Rx, Rz the master points at right ending can fully constraint Uy, Uz and Rx, Rz. A reference rotation angle θ of the same degree, but opposite direction is pushed on those two master points mentioned above to make thebox-beam model vertically bending to break.

The Arc-length method of the nonlinear finite element method can be used to account the ultimate strength analysis of Reckling No. 23 box girder model.



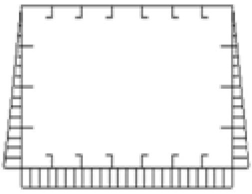


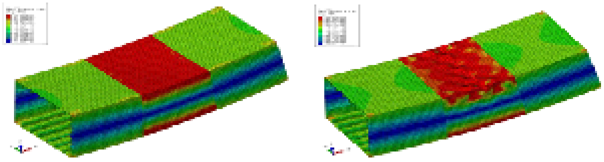
Fig- 3: Boundary condition model **Fig- 4:** Distribution of external water pressure of box girder model

In this paper, the study of ultimate strength of box girder structure under hogging bending moment, torque moment and water pressure simultaneously. The bottom lateral pressure of box girder is 0.124Mpa, and the lateral pressure on both sides obeys the rule of linear distribution as shown in Fig. 4.

The calculation condition mainly is combination of hogging bending moment and torque (Water pressure: P=0 and P=0.124MPa).

3. ULTIMATE STRENGTH OF BOX GIRDER UNDER HOGGING BENDING MOMENT, TORQUE AND WATER PRSSURE

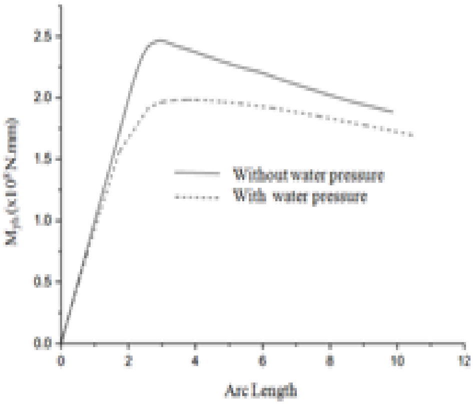
In this paper, the ultimate strength of box girder model under the combined effect (different proportions) of hogging bending moment Myh and torque Mx is calculated. Proportional relation between initial torque Mx and bending moment Myh includes the below several situations: Mx:Myh=0:10, 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, 9:1, 10:0. In which, Mx:Myh=0:10 refers to pure bending condition, and that the rotation angle of master nodes at both ends along X direction shall be constrained. Mx:Myh=10:0 refers to pure torque condition, in which, the rotation angle of master nodes at both ends along Y direction shall be constrained. Deformed shapes and von Mises stress distributions of box girder model structure at the ultimate limit state under sagging bending moment are shown in Fig. 5 The calculation results are shown in Fig. 6.



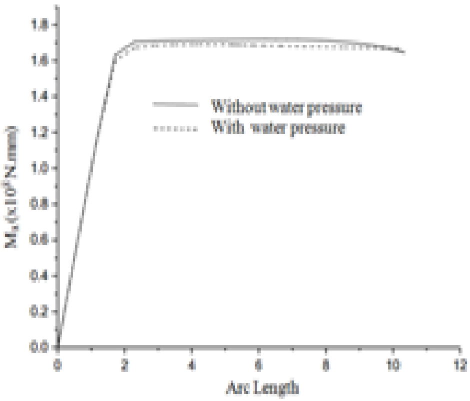
a. Ideal model b. Defective Model

Fig-5: Membrane stress distribution in box girder

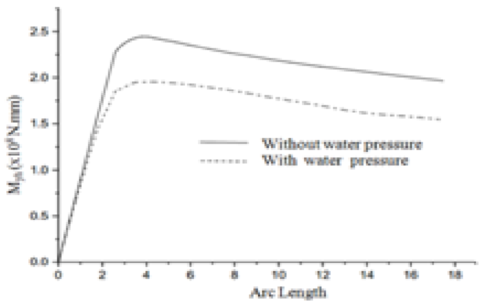
In Fig. 6, the left column refers to arc length - bending moment curve under different calculation conditions, while the right column shows Arc length - torque curve under different calculation conditions. According to the peak value in the above curves, we may be able to figure out ultimate strength hogging bending moment and ultimate torque under different conditions, as shown in Table 2 and Fig. 7.



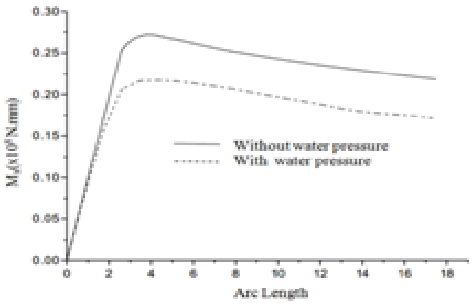
M_xM_{yh}= 0:10



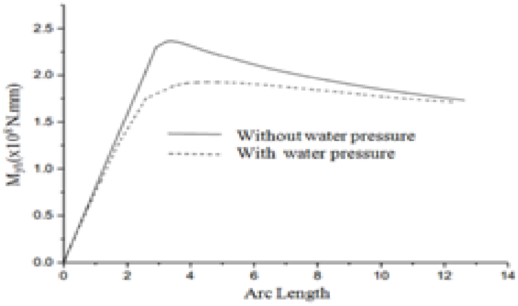
M_xM_{yh}= 0:10



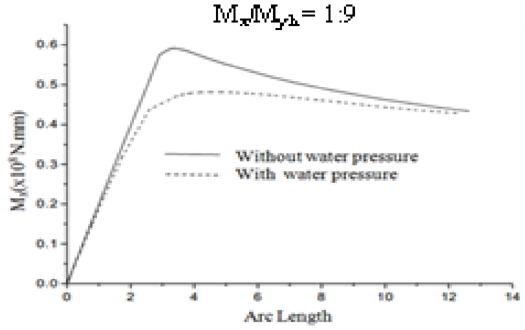
M_x/M_{yh}= 1:9



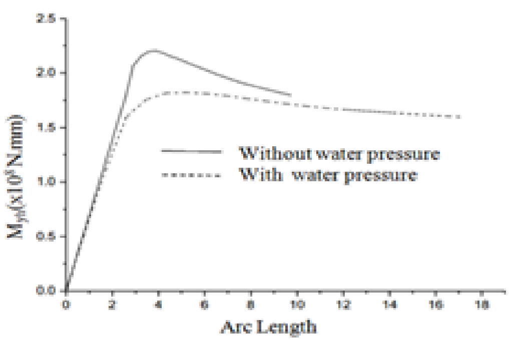
M_x/M_{yh} = 1:9



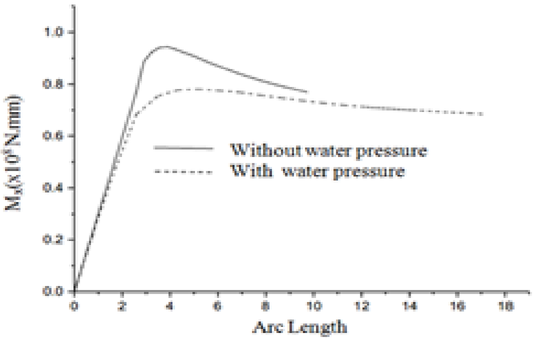
M_x/M_{yh} = 2:8



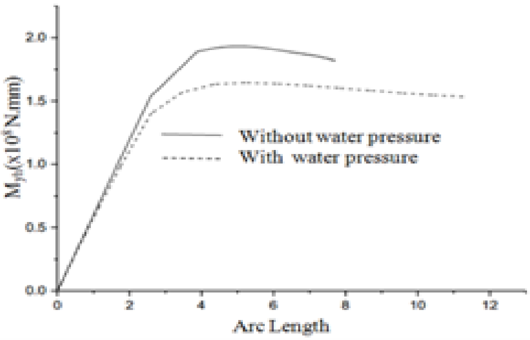
M_x/M_{yh} = 2:8



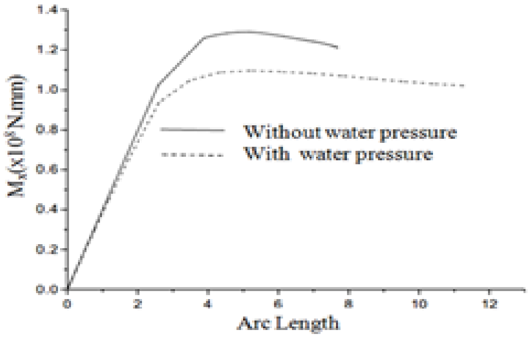
M_x/M_{yh}= 3:7



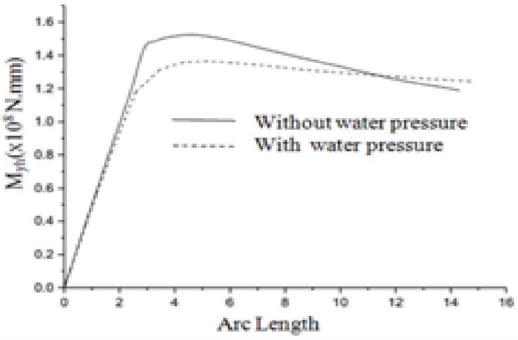
M_x/M_{yh}= 3:7



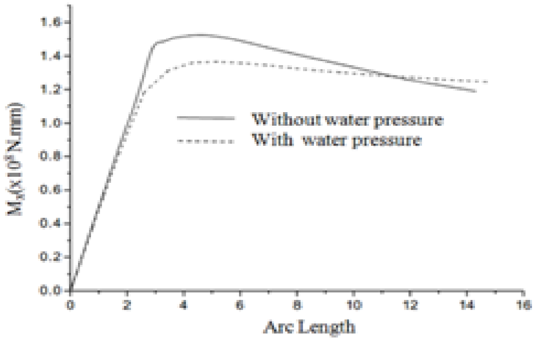
M_x/M_{yh}= 4:6



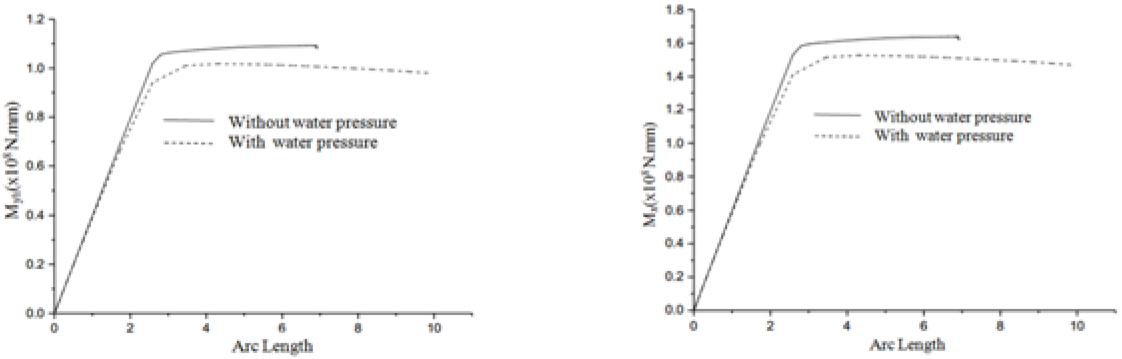
M_x/M_{yh}= 4:6



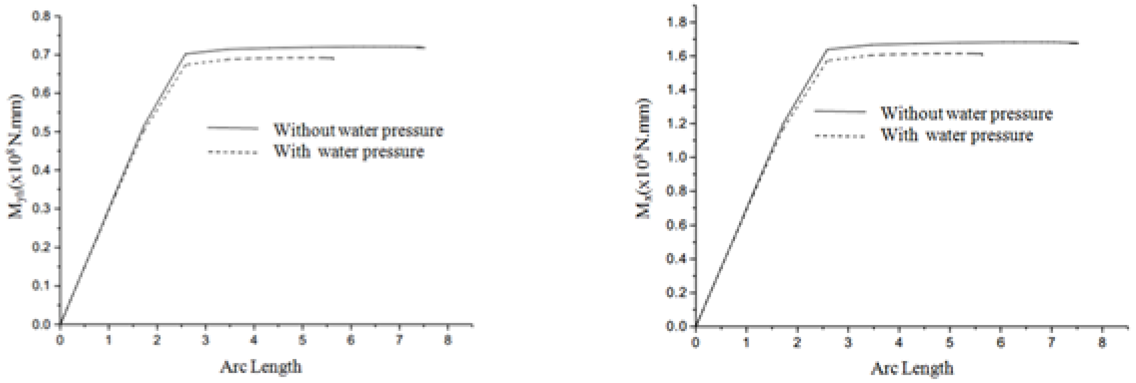
M_x/M_{yh} = 5:5



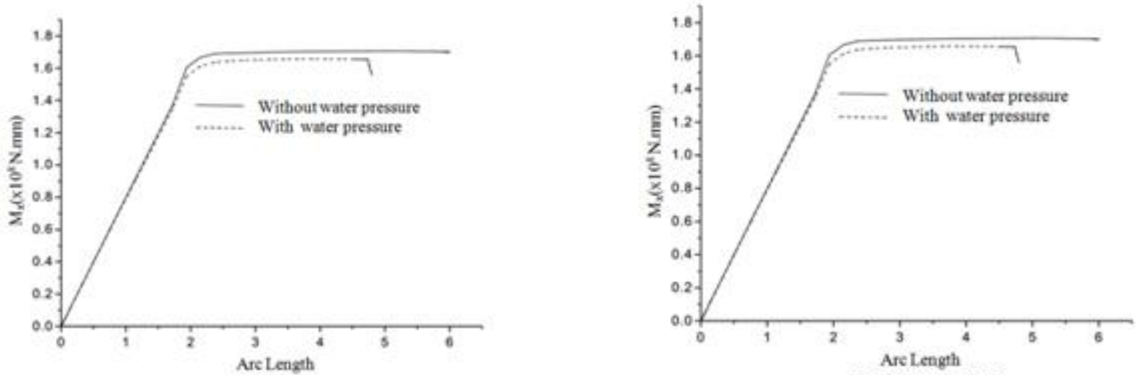
M_x/M_{yh} = 5:5



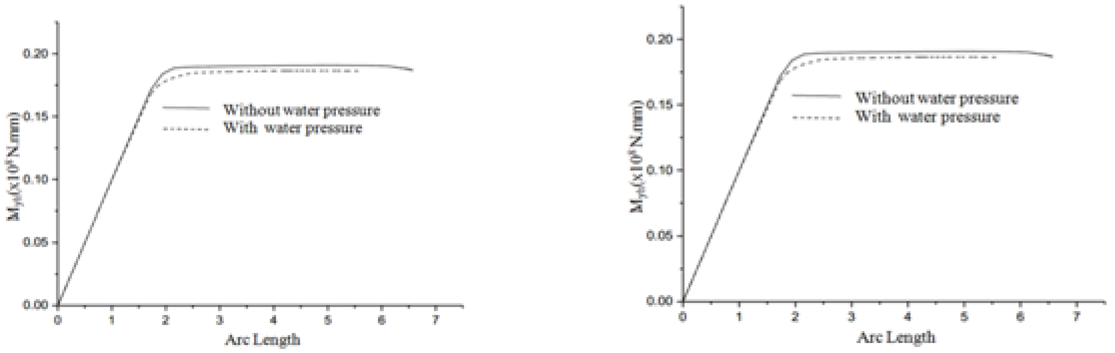
M_x/M_{yh} = 6:4 M_x/M_{yh} = 6:4



M_x/M_{yh} = 7:3 M_x/M_{yh} = 7:3



M_x/M_{yh} = 8:2 M_x/M_{yh} = 8:2

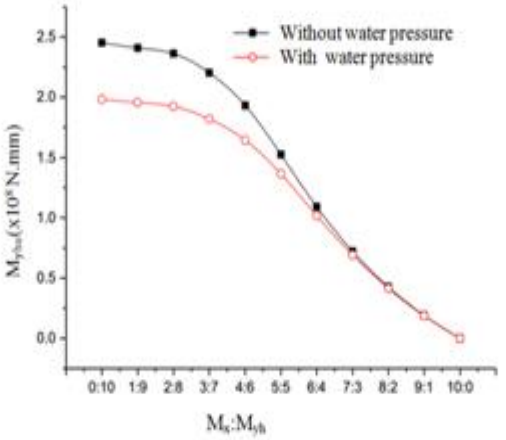


M_x/M_{yh} = 9:1 M_x/M_{yh} = 9:1

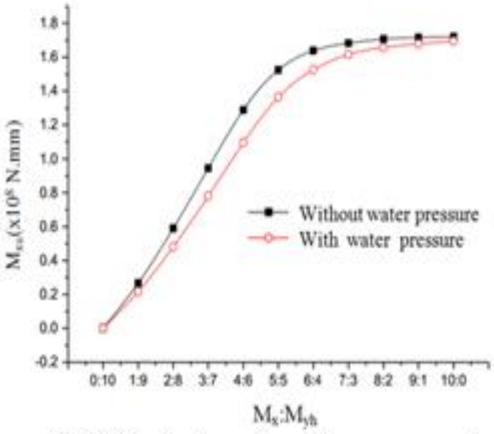
Fig- 6: Arc Length - Bending Moment/Torque Curve under Different Calculation

Table- 2: Calculation results of combined effect of hogging bending moment and torque

Load ratio	**Calculated ultimate strength bending moment**					
	Without water pressure		With water pressure			
M_x:M_{yh}	M_{xu}	M_{yhu}	M_{xu}	Deviation (p=0)	M_{yhu}	Deviation (p=0)
0:10	0.000	2.453	0.000	—	1.984	-19.13%
1:9	0.268	2.409	0.217	-18.83%	1.956	-18.83%
2:8	0.591	2.363	0.481	-18.57%	1.924	-18.57%
3:7	0.944	2.203	0.780	-17.37%	1.820	-17.37%
4:6	1.289	1.933	1.096	-14.96%	1.644	-14.96%
5:5	1.525	1.525	1.365	-10.52%	1.365	-10.52%
6:4	1.638	1.092	1.527	-6.81%	1.018	-6.81%
7:3	1.682	0.721	1.615	-4.00%	0.692	-4.00%
8:2	1.706	0.427	1.657	-2.88%	0.414	-2.88%
9:1	1.716	0.191	1.679	-2.21%	0.187	-2.21%
10:0	1.720	0.000	1.694	-1.50%	0.000	—



(a) Ultimate strength of Hogging bending moment



(b) Ultimate strength of torque moment

Fig-7: Ultimate strength for proportion of different load

Based on the above calculation results, we may reach the following conclusions:

(i) The calculation values of ultimate strength of hogging bending moment M_{yhu} and ultimate torque M_{xu} are consistent to their portions in initial load, i.e. higher proportion of hogging bending moment M_{yh} or torque M_x in initial load leads to larger calculation value of corresponding ultimate hogging bending moment M_{yhu} or ultimate torque M_{xu}.

(ii) Comparing with finite element model of box girder with external lateral pressure p=0 and p=0.124MPa, we may be able to find that, external lateral pressure p leads to negative effect on both ultimate hogging bending moment M_{yhu} and ultimate torque M_{xu} and lateral pressure on ship bottom accelerates hogging deformation. Lateral water pressure may significantly reduce the ultimate strength of stiffened plate of ship bottom. The two factors jointly reduce ultimate hogging bending moment Myhu.

(iii) By researching the calculation results of different conditions, ultimate hogging bending moment and ultimate torque shall have the below relationships:

- Model without water pressure :

$$\left(\frac{M_{xu}}{M_{XU}}\right)^{2.504}+\left(\frac{M_{yhu}}{M_{YHU}}\right)^{2.504}=1 \qquad (1)$$

- Model with water pressure:

$$\left(\frac{M_{xu}}{M_{XU}}\right)^{2.200}+\left(\frac{M_{yhu}}{M_{YHU}}\right)^{2.200}=1 \qquad (2)$$

Where:

M_{xu} -Ultimate strength of torque under combined load of bending moment and torque

M_{XU} -Ultimate strength of torque under pure torque
M_{yhu} -Ultimate strength of hogging bending moment under combined load of bending moment and torque
- M_{YHU} - Ultimate strength of hogging bending moment under pure bending moment

Calculation results of proportionality coefficient M_{xu} /M_{XU} and M_{yhu} /M_{YHU} are shown in Table 3 and Fig. 8.

Table -3: Calculation results of proportionality coefficient

Load ratio	**Calculated ultimate strength bending moment**			
	Without water pressure		With water pressure	
M_x:M_{yh}	M_x/M_{XU}	M_{yh}/M_{YHU}	M_x/M_{XU}	M_{yh}/M_{YHU}
0:10	0.000	1.000	0.000	1.000
1:9	0.156	0.982	0.128	0.986
2:8	0.343	0.964	0.284	0.970
3:7	0.549	0.898	0.461	0.918
4:6	0.749	0.788	0.647	0.829
5:5	0.887	0.622	0.806	0.688
6:4	0.952	0.445	0.901	0.513
7:3	0.978	0.294	0.953	0.349
8:2	0.992	0.174	0.978	0.209
9:1	0.998	0.078	0.991	0.094
10:0	1.000	0.000	1.000	0.000

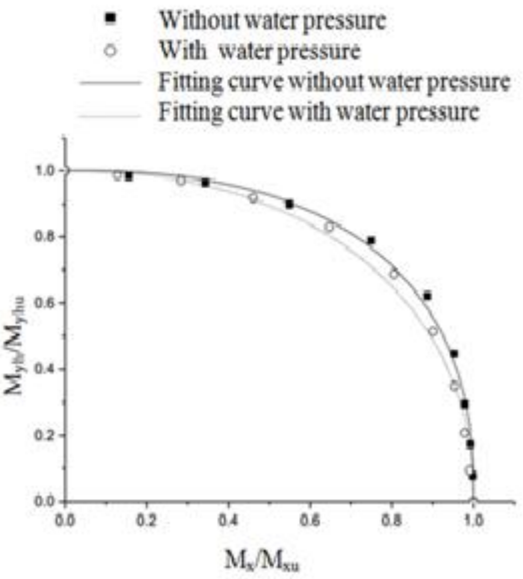


Fig-8: Scatter diagram and fitted curve diagram of proportionality coefficient

4. CONCLUSIONS

With No. 23 box girder model as the research object, this paper has studied the ultimate strength of such model under combined load.

- Nonlinear finite element method leads to high precision when being applied to calculate the ultimate strength of structure. Especially if initial deflection is considered, the calculation results would be consistent to the test values.
- The relationship between ultimate torque and ultimate bending moment may be described with the below expression:

Model without water pressure :

$$\left(\frac{M_{xu}}{M_{XU}}\right)^{2.504}+\left(\frac{M_{yhu}}{M_{YHU}}\right)^{2.504}=1$$

Model with water pressure:

$$\left(\frac{M_{xu}}{M_{XU}}\right)^{2.200}+\left(\frac{M_{yhu}}{M_{YHU}}\right)^{2.200}=1$$

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