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DESIGN OF RADIAL GATE USING RECTANGULAR AND I SECTIONS – A Case Study

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ABSTRACT

A reservoir is an artificial lake where water is stored. The dam controls the amount of water that flows out of the reservoir. Spillways are structures constructed to provide safe release of floodwater from a dam to a downstream side of the river. The Radial gate is a type of arm gate used in dams and canal locks to control water flow. Present work has carried out a methodology to develop an optimal design of Radial gate with alternative steel sections and different grades of steel. To develop an optimal design of gate three different grades of steel ASTM A36, ASTM A992 and ASTM A653 were analysed and ASTM A653 grade of steel used for skin plate of radial gate.In order to reduce the weight of gate, two design of radial gate one with conventional I section and another with combination of unconventional rectangular hollow section and conventional I section prepared and analysed using a design and analysis software SAP2000. The efforts are made to reduce the weight of gate. After the analysis of gate, it is seen that the weight of gate is reduced by 23% In addition; optimization of gate can be done by using both conventional and unconventional design sections for various members of the radial gate.

Keywords- *Spillway Gate, Radial Gate, SAP2000, Finite Element Analysis*

1. INTRODUCTION

The Radial gate is a type of floodgate with arms used in dams and canal to control water flow. A side view of a Radial gate resembles as a slice of circle. The curved part of the gate face the upper level of water and the tip pointing toward the lower level of pool. The curved portion or skin plate of the gate takes in the form of a triangular shaped section of cylinder. The straight sides, the trunnion arms, extend back from the ends of the cylinder sections and meet at a trunnion hub, which serves as a pivot point when the gate rotates. The Pressure forces on a submerged body act perpendicular to the surface of body. The design of the Radial gate results in every pressure force acting through the centre of the imaginary circle, which the gate is a section of, so that all resulting pressure force acts through the pivot point of the gate. It makes construction and design easier. When a radial gate is closed, water load bears on convex (upstream) side and when the gate is rotated, the rush of water passing under the gate helps to open the gate. The rounded face, long radial arms and trunnion bearings allows the gate to close with less effort than other gates. Radial gate are usually operated from above with a gearbox, chain, or electric motor assembly. In designating the size of a radial gate, the width is given first then allocates the height. Height is the vertical distance projected from the sill level to the top of the gate. The opening, which covers in the vent between piers is the height of that gate. It is not the curved length of the gate. Sill is generally located downstream of the spillway crest to improve flow condition and avoid cavitation on the downstream glacis.

1.1 SKIN PLATE

The skin plate of a radial gate is made up of skin plate bent into the shape of an arc. Thrust of water is taken by the convex face of gate. The radius of curvature of gate is generally H to 1.25H, where H is the vertical distance between the sill and the top of gate. A 1.5 mm corrosion allowance is provided while deciding the thickness. The skin plate assembly is fabricated in segments so that they are conveniently transported and assembled at site. The skin plate is provided with either vertical or horizontal stiffeners.

1.2 HORIZONTAL GIRDERS

Horizontal girders are provided to take up the water thrust from the skin plate. Horizontal girders are generally plate girders, which has webs, web stiffeners and flanges. Drain holes are provided to prevent the water collection, which causes rusting.

1.3 RADIAL ARMS

Radial arms start from the trunnion hub and are connected to the vertical end supports of skin plate. In case of small size gates connected to horizontal girders. There are two types of arm assemblies such as Parallel arms and inclined arms.

1.4 TRUNNION ASSEMBLY

Trunnion assembly consists of trunnion hub connected to the arms, trunnion pin acting as a hinge, and trunnion bracket mounted on anchor girders. If the gate is designed with inclined arms, side thrust due to inclined arms could be tackled by suitable anchorage such as by providing the tie girder between two trunnions of a gate. Trunnion hub is a complicated and heavy steel casting. The castings of trunnion assembly are to be thoroughly checked for soundness. blow holes and cracks should be avoided. Generally, phosphor-bronze bearing metal bushing is fitted to trunnion hub. Generally, Trunnion pins are of cast steel or forged carbon steel with hard chrome or nickel plating to reduce rusting, friction and wear.

1.5 ANCHORAGE SYSTEM

The trunnion rests on an anchor girder, which is held on the concrete of the spillway pears by the set of tie flats. The total water thrust exerted on the gate is transmitted to the piers as bond stress between tie flats and concrete of the pier. Hence, the anchor bars are in full contact with concrete. Generally, a simple box type girder spanning the pier width, is provided and the trunnions are mounted at either end. Each anchor girder holds trunnion of two adjacent gates. The anchor girders are held in position and connected to the pier by tie flats of suitable width and length.

1.6 END FRAME BRACING

The end frame bracing members are designed to brace the struts about the weak axis to achieve adequate slenderness ratios. As such, these members are considered secondary members. However, depending on their configuration and connection details, these bracing members may carry significant forces and act as primary members.

2. OPTIMIZATION

Structural optimization is a method for optimizing the layout of materials in a structure. Therefore, it is also called layout optimization. It is a powerful computational tool in structural design in addition to size/shape optimization. In optimization, both the amount and layout of the material in the design domain can be changed freely.

2.1 CASE STUDY PROBLEM

The Man Project is major irrigation project. It is one out of the 29 major projects, which identified in the Narmada Master Plan for implementation. The Man project site is about 2 km from village Jeerabad located on Khalghat-Manawar-Amjhera district road and is about 22 km from Manawar. The project provided irrigation in an area of 15000 hectares of 53 villages of Manawar, Gandhawani&Kukshi Tehsils of Dhar district, Madhya Pradesh. This project has a gravity dam across the river Man, a tributary of river Narmada near village Jeerabad. The data given below are acquired form the Narmada Valley Development Department (N.V.D.D) website. *nvda.mpforest.org/NVDA-website*

Table 2.1- Dimensions of Radial Gate.

COMPONENT	VALUE
Height (H)	12 m
Width (W)	12 m
Radius Of Gate	13.2 m
Angle (radial arm)	39º65”
Arc length of skin plate	12.457 m
Trunnion Distance From Crest	11.758 m
Trunnion Height From Crest	6 m
Distance Between Radial Arms	10.50 m

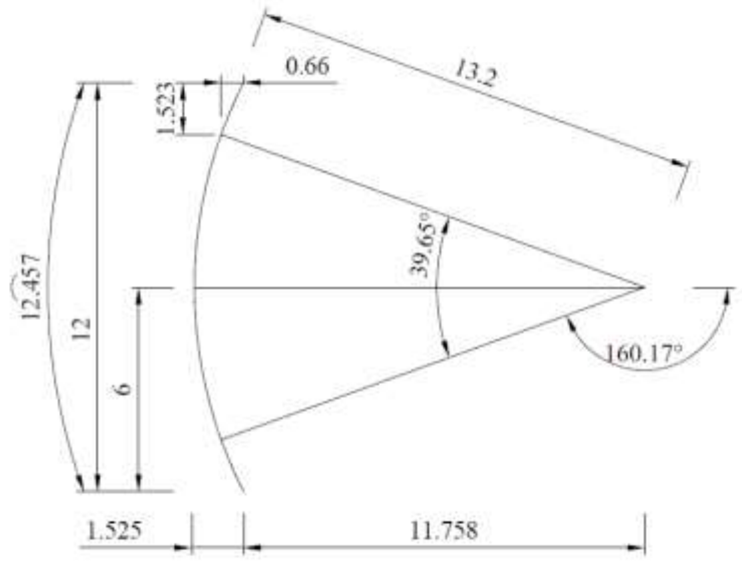

Fig. 2.1 - Dimensions of Radial Gate

2.2 DESIGN AND ANALYSIS PROCESS

Design of radial gate involved various parameters and dimensions. In present study dimension of Man gravity dam is considered to develop a Radial gate design. The site data of Man dam provided various levels of Dam. On the basis of present data, a suitable dimension of radial gate are obtained. The obtained dimension of radial gate are fulfilled the various design consideration of radial gate which are given in IS 4623:2000 a radial gate design code.

As the present study is focused on developing an optimal design of radial with the uses of unconventional design sections, thus the two different design of radial gate prepared one with the conventional I section and other one with conventional as well as unconventional design sections. A model of radial gate is developed in SAP2000 by using the design data, which obtained from the Man project site. The details of model development are discussed in this chapter. Different model of radial gate are developed and then analysed In SAP2000, under the different operating condition and load. SAP2000 is a structural design and analysis software, which is used Finite Element Method (FEM) to analyse the developed model.

2.3 MEMBERS CROSS-SECTION

In present study for Case-1 a typically I cross-section beam is used for conventional design of radial gate, and in Case-2 for design of radial gate with conventional I section and unconventional rectangular hollow cross-section beam are used. I beam are widely used in the construction and I beams are available in variety of standers in market. Different standard of I beam has the different cross sections.

Table 2.2 - Details of Rectangular Members

PROPERTIES	ISB 72X72X4.8	ISB 91.5X91.5X3.6	ISB 122X61X3.6
Weight per Meter (w)	9.82 kg/m	9.76 kg/m	9.76 kg/m
Sectional Area (a)	12.31 cm2	12.32 cm2	12.32 cm2
Depth of Section (h)	72 mm	91.5 mm	122 mm
Width of Section (b)	72 mm	91.5 mm	61 mm
Thickness of Section (t)	4.80 mm	3.60 mm	3.60 mm
Outer surface (Area per M)	0.263 m2	0.347 m2	0.347 m2

Table 2.3 - Details of I-Beam Sections

PROPERTIES	ISLB175	ISLB300	ISLB350	ISMB600	ISHB300	ISHB450	ISWB600
Weight per Meter (w)	164 N	370 N	472 N	1210 N	577 N	869 N	1312 N
Sectional Area (a)	21.30 cm2	48.08 cm2	63.01cm2	156.21 cm2	75.85 cm2	111.14 cm2	170.38 cm2
Depth of Section (h)	175 mm	300 mm	350 mm	600 mm	300 mm	450 mm	600 mm
Width of flange (b)	90 mm	150 mm	165 mm	210 mm	250 mm	250 mm	250 mm
Thickness of Flange (t_f)	6.9 mm	9.4 mm	11.4 mm	20.8 mm	10.6 mm	13.7 mm	21.3 mm
Thickness of Web (t_w)	5.1 mm	6.7 mm	7.4 mm	12.0	7.6 mm	9.8 mm	11.2 mm

2.4 MATERIALS

In present study different grade of steel are analysed and compared, then Three different grade of steel are selected and by comparing their result one most suitable material is chose to design the radial gate. The details of different grade of steels are given in following table.

ASTM A36 - Structural Shapes and Plate **(Carbon Steels)**

ASTM A992 - Structural Shapes and Plate **(High Strength Low Alloy Steels)**

ASTM A653 - Structural Shapes and Plate **(Cold-Formed Structural Steels)**

Table 2.4 - Details of Different Grade of Steels

PROPERTIES	ASTM A36	ASTM A992	ASTM A653
Density ρ	7.85 g/cm3	7.85 g/cm3	7.85 g/cm3
Tensile Strength, Ultimate (Fu)	400 MPa	448.15 MPa	448.15 MPa
Tensile Strength, Yield Fy	248 MPa	344.73 MPa	344.73 MPa
Modulus of Elasticity	200 GPa	200 GPa	203.3 GPa
Poisson Ratio µ	0.3	0.3	0.3
Shear Modulus	76.90 GPa	76.90 GPa	78.22 GPa

3.0 RESULT AND DISCUSSION

three grades of steel (ASTM A36, ASTM A992, ASTM A653) are used. These materials are analysed under same load condition and checked for hydrostatic force. Different grade of steel are analysed under hydrostatic load using SAP2000

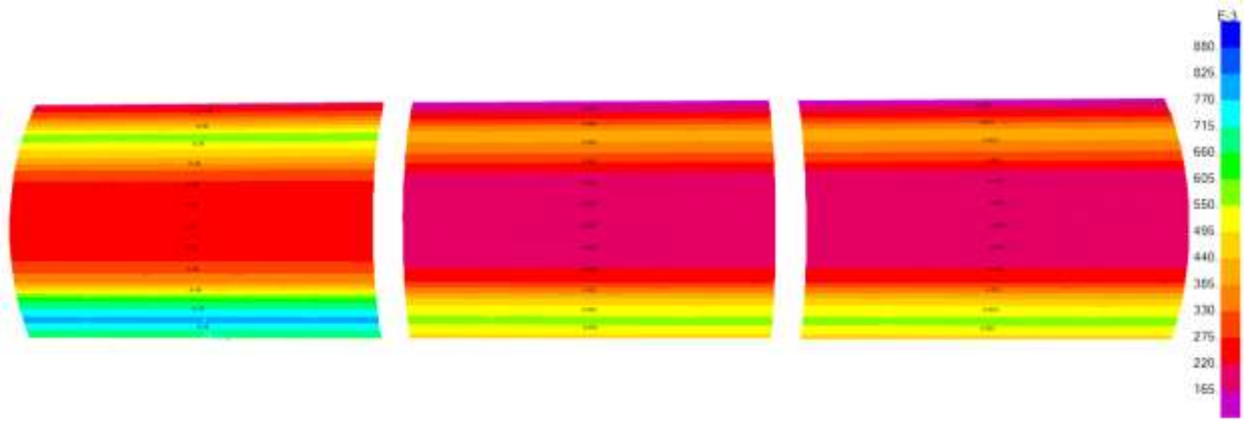

Fig. 3.1 - SVM (Normalize stresses by materials strength) for different Steel Grades

3.1 RESULT OF DESIGN ANALYSIS OF RADIAL GATE (WITH UNCONVENTIONAL SECTION)

Design of Radial Gate analysed under two-load cases, Case-1 is the combination of Hydrostatic and dead load and Case-2 is the combination of Hydrodynamic and dead load. Load Case-1 is applied when gate is in sill level and load Case-2 is applied for operating condition. The model of radial gate designed with conventional I and unconventional rectangular hollow sections and it is analysed for both load cases.

Hydrodynamic Load + Dead Load (When Gate Is In Operating Condition)

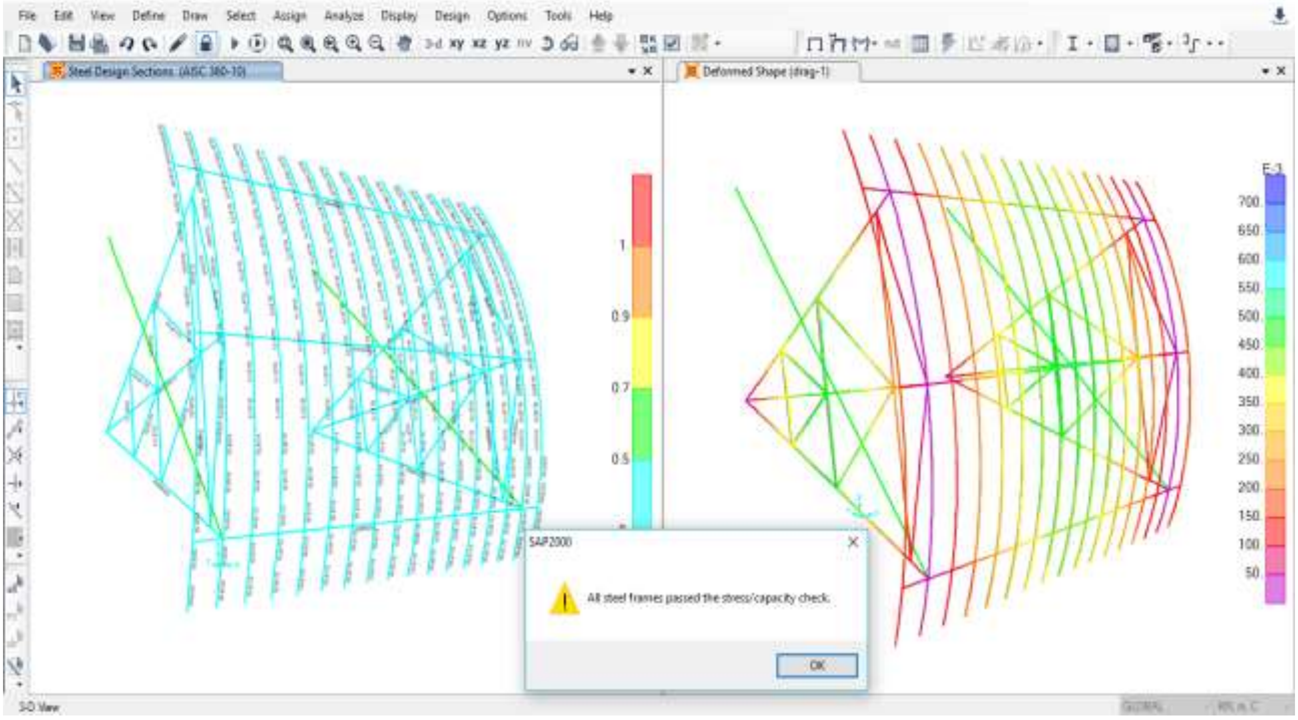

Fig.3.2- Analysis of Radial Gate in Operating Condition and Its Deformed shape

Deformed shape of radial gate under the combination of Hydrostatic and dead load for resultant contour component are shown as follow.

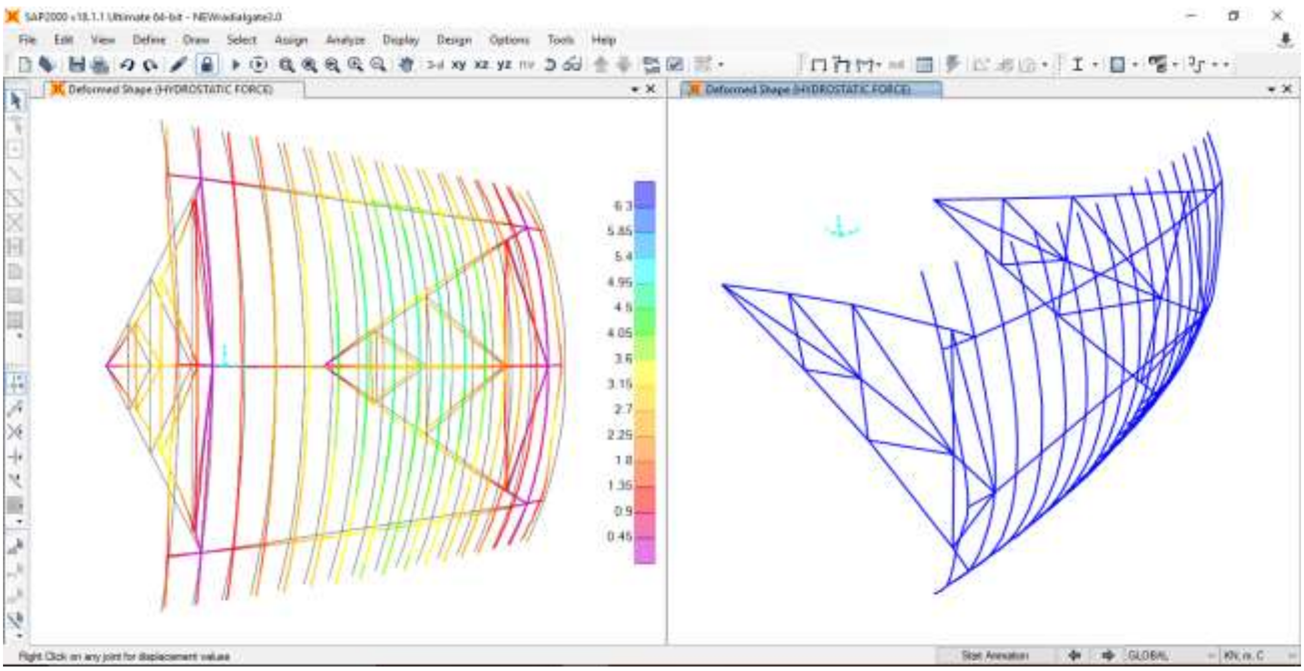

Fig. 3.3 - Deformed Shape of Radial Gate

3.2 Resultant Forces and Shell Stresses

The resultant forces, maximum principal moment and maximum principal shear occurred due to load case 1 and shell stresses, which are developed due to these forces, are shown in followingFig.

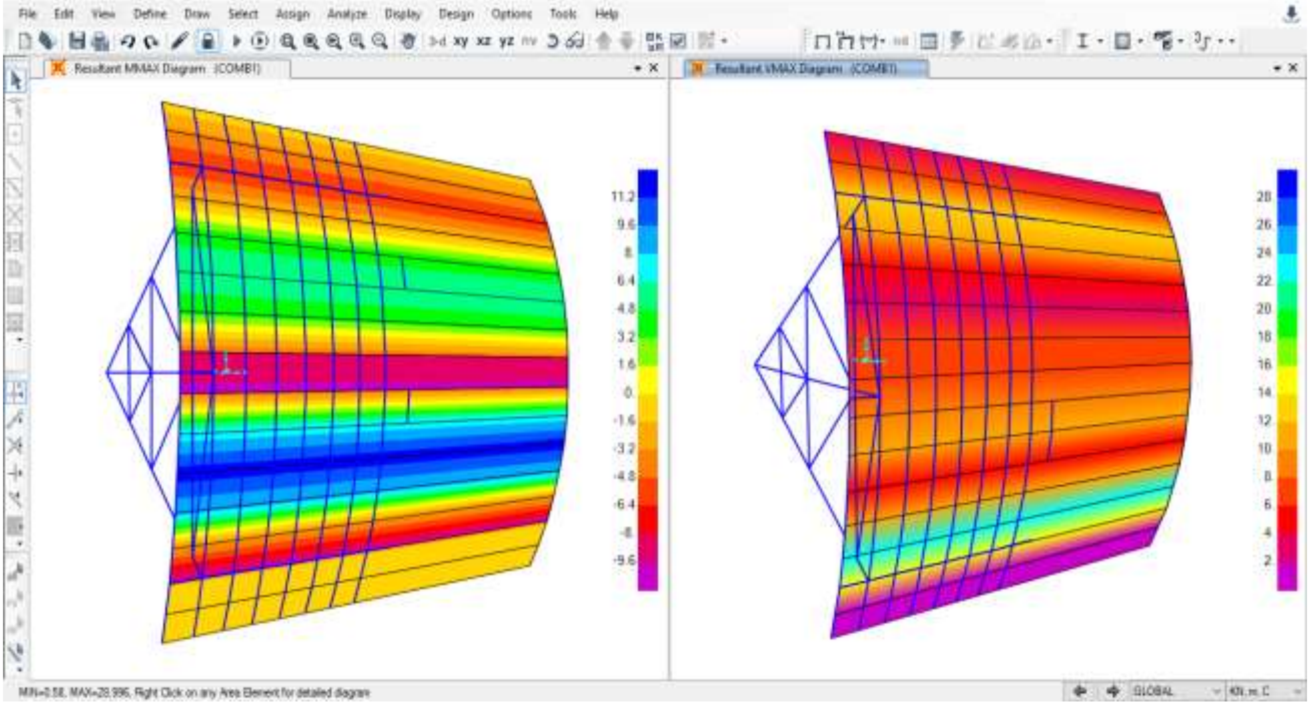

Fig. 3.4 -MmaxandVmaxof Radial Gate

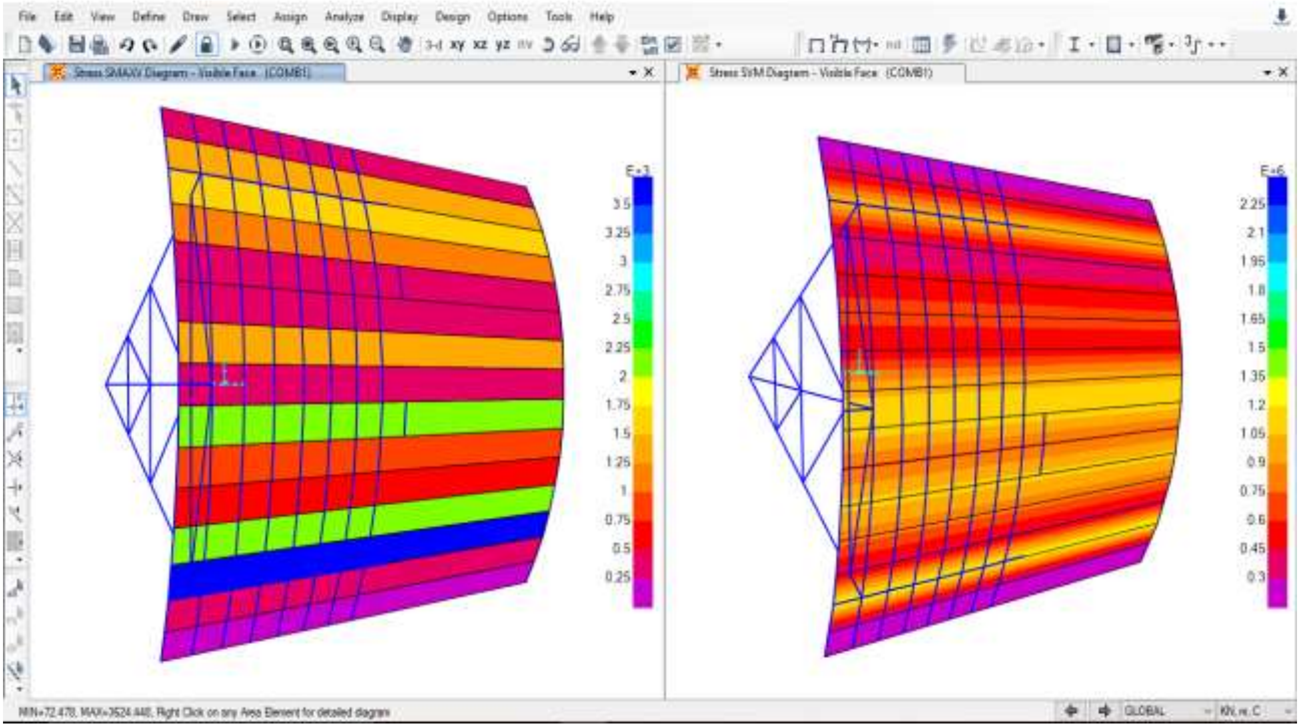

Fig. 3.5 - SVM and SmaxV Stress of Radial Gate

The design of radial gates one with conventional I steel sectionand anther one with unconventional rectangular and conventional I section are prepared and analysed by using SAP2000 under different load cases. The weight of radial gate for both designs cases are shown below.

Table 3.1 - Details of Members Weight of Conventional Radial Gate

GROUP NAME	**Self-Mass** KN-s2/m	**Self-Weight** KN	**Total Mass X** KN-s2/m	**Total Mass Y** KN-s2/m	**Total Mass Z** KN-s2/m
All	29.7	**291.21**	29.7	29.7	29.7
Skin Plate	9.39	92.05	9.39	9.39	9.39
Skin Frame	4.59	44.992	4.59	4.59	4.59
Horizontal Member	4.55	44.595	4.55	4.55	4.55
Main Frame	8.14	79.786	8.14	8.14	8.14
Stiffener	3.04	29.787	3.04	3.04	3.04

Table 3.2 - Masses and Weights (Rectangular and I – section)

Group Name	**Self-Mass KN-s2/m**	**Self-Weight KN**	**Total Mass X KN-s2/m**	**Total Mass Y KN-s2/m**	**Total Mass Z KN-s2/m**
ALL	22.64	**222.064**	22.64	22.64	22.64
skin plate	9.39	92.05	9.39	9.39	9.39
skin frame	2.05	20.072	2.05	2.05	2.05
horizontal member	2.24	21.987	2.24	2.24	2.24
main frame	8.14	79.786	8.14	8.14	8.14
Stiffener	0.83	8.169	0.83	0.83	0.83
horizontal member-1	1.74	17.075	1.74	1.74	1.74

4.0 CONCLUSIONS

A hollow rectangular section is used in radial gate as vertical stiffeners by replacing conventional I sections. 64 KN, which is 23.3% of weight of Radial gate, is reduced by using rectangular members section over I section. ASTM A653 cold formed steel shows less normal stress and shear stress then the ASTM A36 or ASTM A992 grade of steel under same load conditions. ASTM A653 (cold formed steel) increases capacity of structure to resist stress and shows better durability. The design of gate can be optimise by using both conventional and unconventional section for various members of gate. The manual calculation method are highly time consuming, tedious, repetitive. SAP2000 is a simple, powerful and productive tool for structure analysis.

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