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Research Article

Basic Analysis of Skew Plates with Openings

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Abstract

Skew plates are important elements of many structures. The two-dimensional structural action of plates results in lighter structures and therefore offer numerous economic advantages. Their application is extensive in fields of engineering such as: civil, mechanical, architecture, and aerospace. Openings of various shapes are made in the skew plates for practical reasons. Unfortunately, this results in strength degradations. Accordingly, there is a basic need to evaluate the structural behavior of these plates with some commonly used openings for a safe design. However, due to the mathematical difficulties in the analytical approaches and complex work involved in the various techniques, the extraction of solutions become challenging and cumbersome. Therefore, this basic work attempts to resolve this in a simplified and user-friendly manner using MSC (MacNeal-Schwendler Corporation) Nastran software. Five commonly used openings were used for the study, namely: circular, rectangular, square, triangular, and trapezoidal. It was found that rectangular opening is the best. Since it is susceptible to less deflections, rotations and moments when compared to other openings.

Keywords

Skew Plates, Openings, Deflections, Rotations, Moments, Software

1. Introduction

A plate is a structural element that has a small thickness compared to the plane dimensions [1]. The two-dimensional structural action of plates results in lighter structures and therefore offers economic advantages [2]. Loaded plates are extensively used in all fields of engineering and therefore require analyses [2].

The tremendous potential of skew plates as an engineering structure has attracted attention of many researchers [3-13]. An investigation [3] to study the buckling of skew plates subjected to uniform compressive load revealed that critical buckling load value depends on length to width ratios and skew angles. Increasing the ratio and angle caused an increase in the value of critical buckling load. Another investigation to study [4] the effect of skew angle and transverse loading to the buckling behavior revealed that buckling load is proportional to the skew angle [4]. The buckling mode may change a little with the change in the skew angle. Under biaxial loading, the buckling load is increased with magnitude of transverse tensile load [4]. The buckling behavior of composite skew plate with varying skew angles, boundary conditions and linear loading has been investigated [5]. It was found that the buckling load increases with an increase in skew angle. A change in mode shape of the structure is also observed with an increase in angle. Deflection behavior of thin isotropic skew plates under uniformly distributed load for various boundary conditions under flexural loading was studied [6]. An analytical approach using the principle of minimum potential energy was carried. It was found that the

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analytically developed deflection plots can be used to study the effect of boundary conditions. Deflection studies [7] were carried out on skew plates subjected to uniformly distributed load/concentrated load for simply supported boundary conditions using MSC/NASTRAN. It was found that deflection decreases with skew angle. Static response of a graded material plate was studied [8] using shear deformation theory. Important insights into central deflections and stresses were gained. Three-dimensional displacement and stress components in the functionally graded plates were studied [9] using a scaled finite element method along with an integration-based program. The accuracy of semi-analytical procedure was established by comparing with the classical plate theory. Plates with various shapes of openings under varying loads as non-shear, partial shear and pure shear conditions were studied [10] for stress concentrations. Finite element method was used for analysis. It was found that the plates had more stress concentrations around the holes for pure shear loads. Stress behavior of functional plates with a circular hole subjected to a uniaxial traction were studied [11]. It was found that stress decreased with an increase in stiffness ratio. Buckling behavior was studied [12]. It was found that material composition changed in thickness direction. Electro-mechanical response of composite plates was studied [13]. Minimum potential energy along with Navier's technique were used in the analysis. The solution yielded deflections and stresses.

2. Defining the Problem

The main goal of this work is to evaluate the structural behavior of skew plates with some commonly used openings for in a simplified and user-friendly manner. Five commonly used openings were used for the study, namely: circular, rectangular, square, triangular, and trapezoidal. The structural behavior of the plates is evaluated in the context of deflections, rotations, and moments using MSC (MacNeal-Schwendler Corporation) Nastran software.

3. Loads and Dimensions of Skew Plates

Skew Plates with various shapes of openings were analyzed using MSC Nastran package by preparing input file for each type of plate and then executing the file to obtain results like deflections, rotations, and moments in the plates with openings. This section consists of solutions of skew plates with openings. As described earlier, five commonly used openings were used for the study, namely: circular, rectangular, square, triangular, and trapezoidal.

For all plates the loads taken were as follows:

a) Dead load (Self weight + floor finish load on plate)

b) Live load on plate

Dimensions of a typical skew plate used in the analysis are shown in Figure 1.

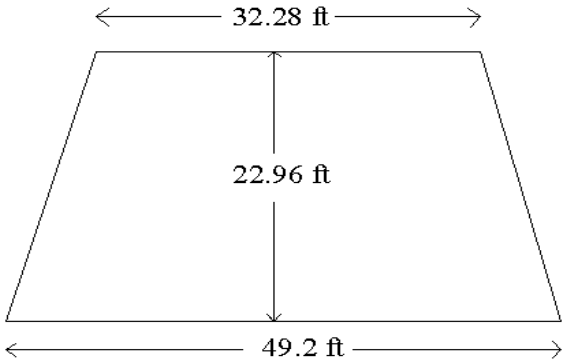

Figure 1. *Dimensions of a Typical Skew Plate.*

The loading conditions and other properties were kept constant for the analysis. However, only the dimensions of the openings were changed.

4. Computations and Comparisons

In this work we studied five cases. The cases with their respective images are shown below. The opening that is least susceptible to less deflections, rotations, and moments may be used for the field work. This evaluatory design is not for a specific component of structure and therefore no direct specifications are available in American codes. Accordingly, typical values are used.

4.1. Skew Plate with Circular Opening Clamped on All Edges

Thickness of plate = 0.492ft

Diameter of the circular opening = 14.76 ft

28- day compressive strength of concrete ($f`_c$) = 4000 psi;

Poisson's ratio (μ) = 0.15; concrete modulus

(E_c) = $5000\sqrt{(f`_c)}$ = $5000\sqrt{4000}$ =316227.7 psi

The minimum calculated loads were:

Dead load (Self weight + Floor finish load on plate) = thickness of plate × unit weight of concrete = 0.492 ft * 0.150 kips/ft ^{3}+ 0.015kips = 0.0888 kips/ft ^{2}

Live load = 0.0630 kips/ft ^{2}

Therefore, total load on plate = 0.1518 kips/ft ^{2}

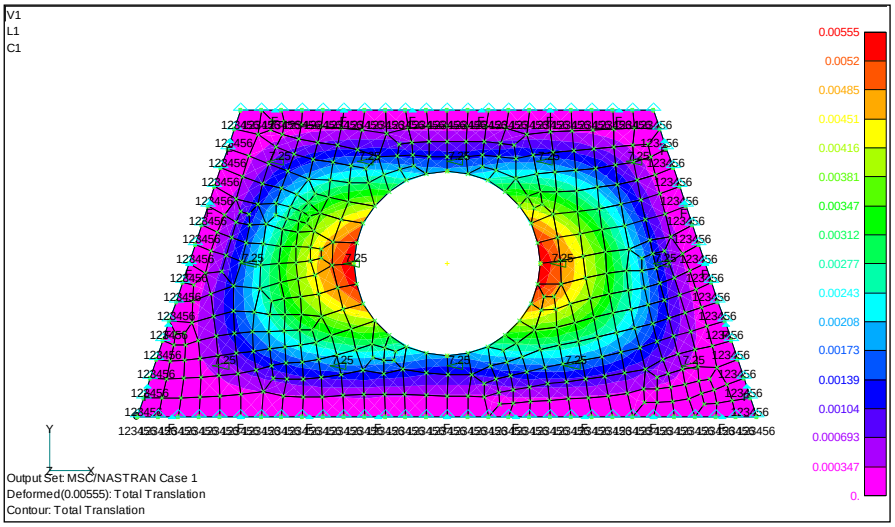

Figure 2. *Deflection Diagram of Skew Plate with Circular Opening.*

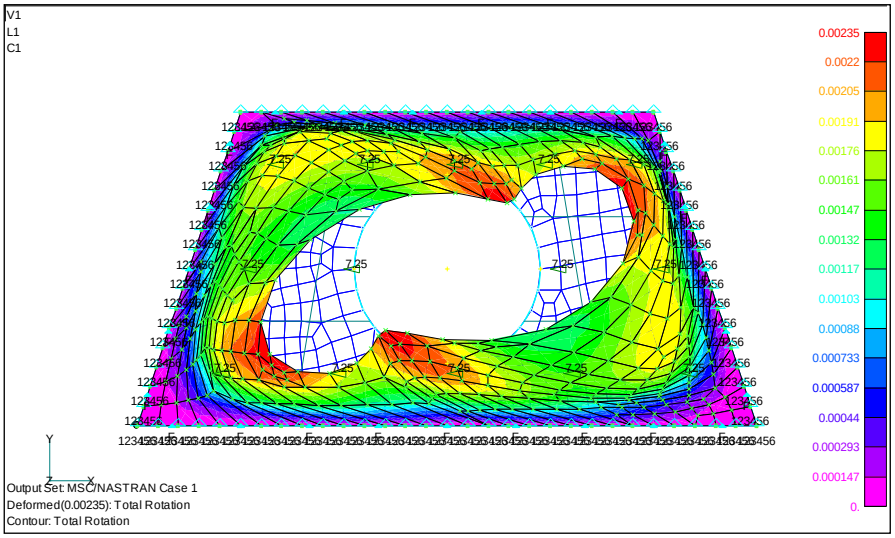

Figure 3. *Rotation Diagram of Skew Plate with Circular Opening.*

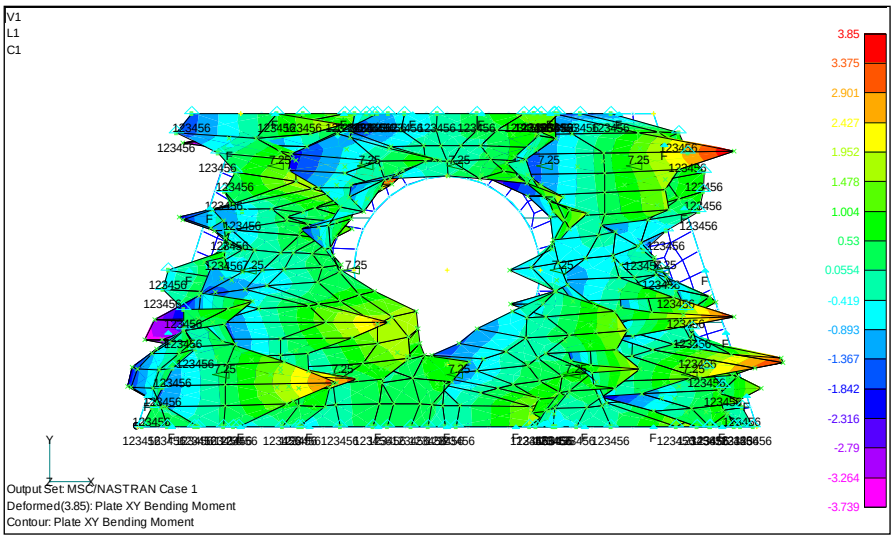

Figure 4. *M_{xy} Diagram of Skew Plate with Circular Opening.*

4.2. Skew Plate with Square Opening Clamped on All Edges

Length of the square opening = 3.96 ft

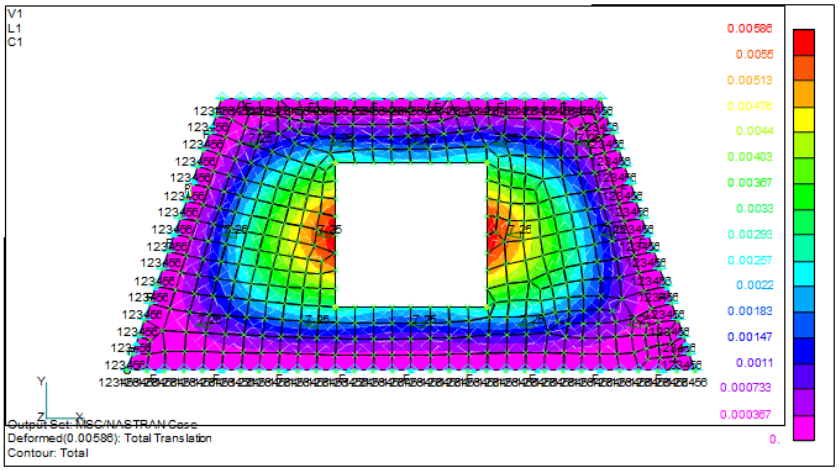

Figure 5. *Deflection Diagram of Skew Plate with Square Opening.*

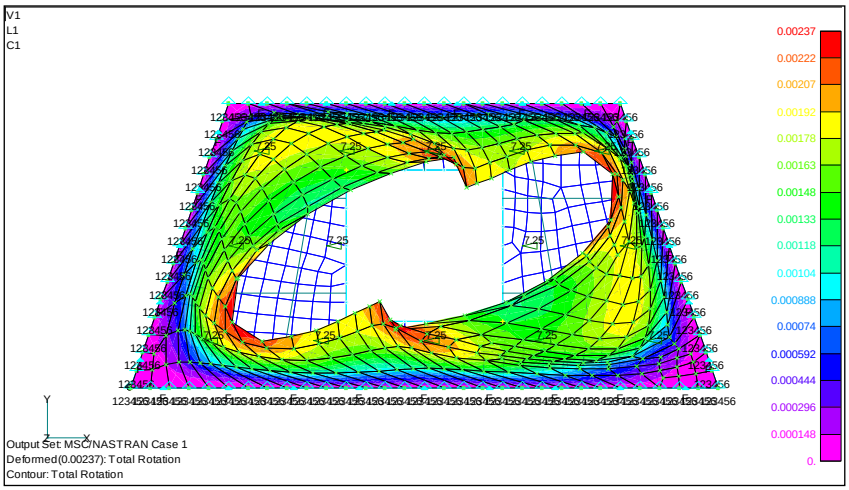

Figure 6. *Rotation Diagram of Skew Plate with Square Opening.*

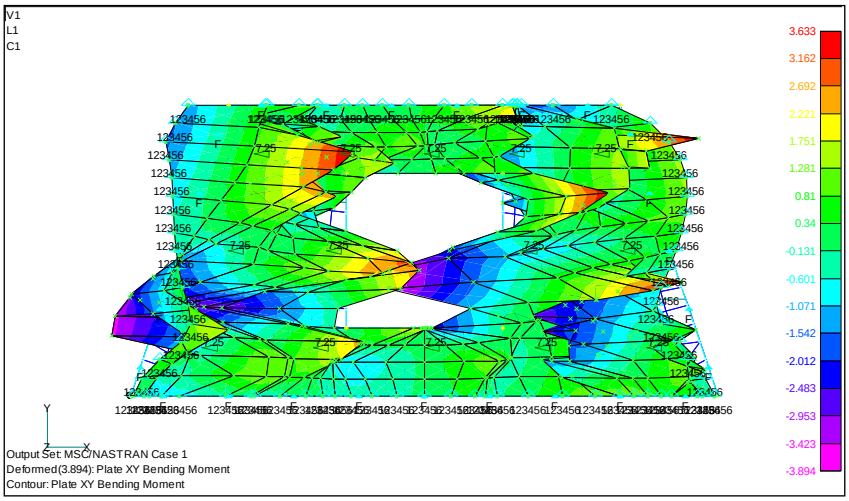

Figure 7. *Mxy Diagram of Skew Plate with Square Opening.*

4.3. Skew Plate with Rectangular Opening Clamped on All Edges

Longer length = 15.5 ft Shorter length = 11 ft

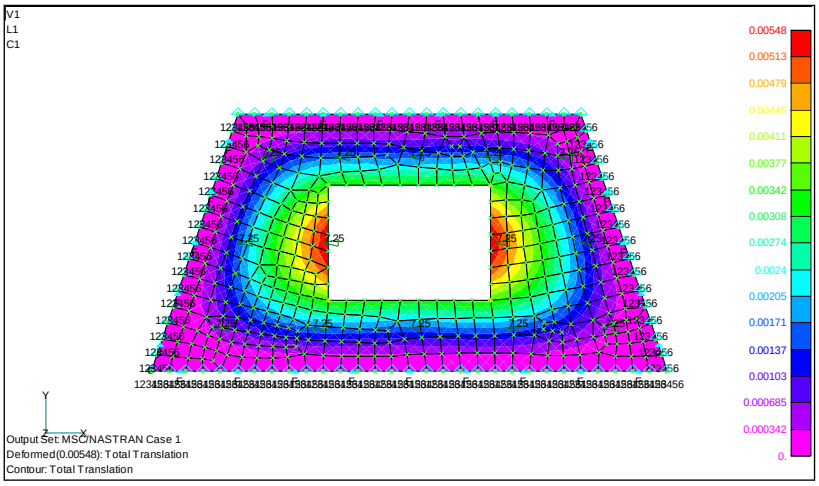

Figure 8. *Deflection Diagram of Skew Plate with Rectangular Opening.*

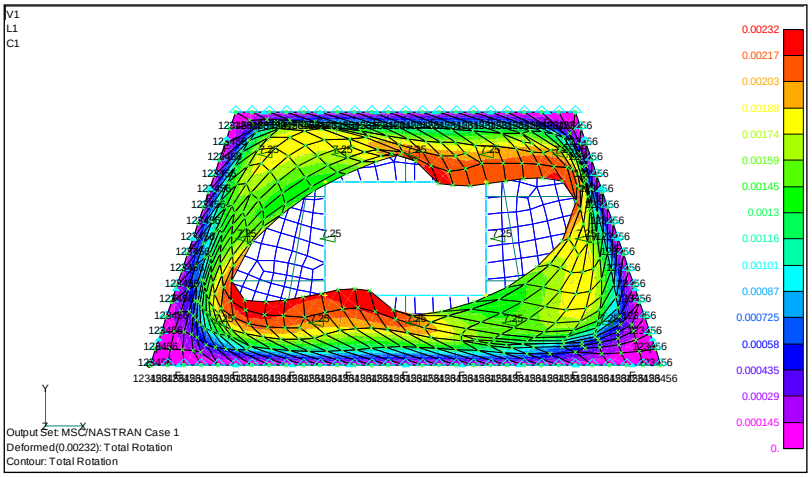

Figure 9. *Rotation Diagram of Skew Plate with Rectangular Opening.*

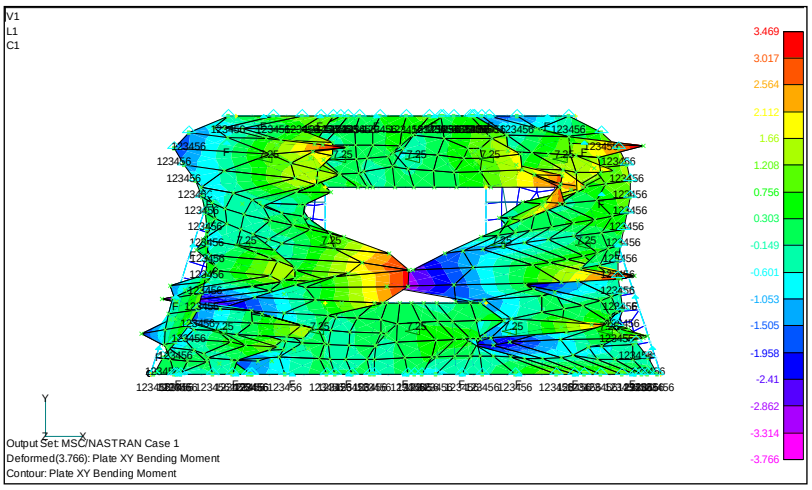

Figure 10. *M_{xy} Diagram of Skew Plate with Rectangular Opening.*

4.4. Skew Plate with Triangular Opening Clamped on All Edges

Base width of triangular opening = 18.5ft and vertical height = 18.5 ft.

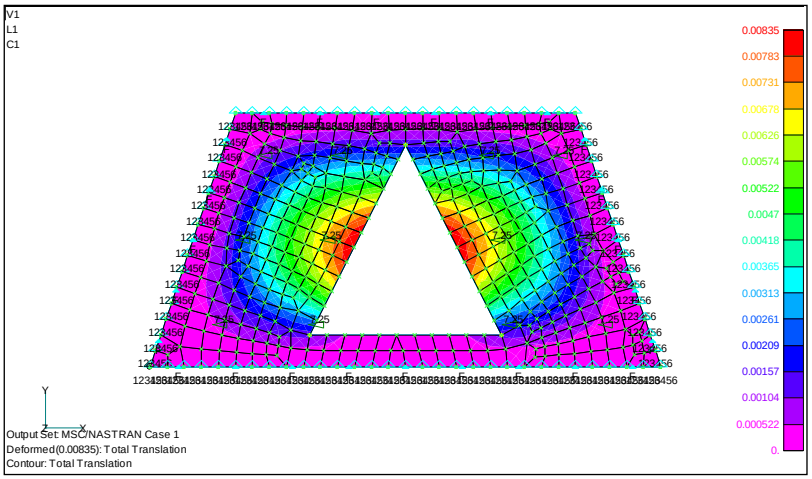

Figure 11. *Deflection Diagram of Skew Plate with Triangular Opening.*

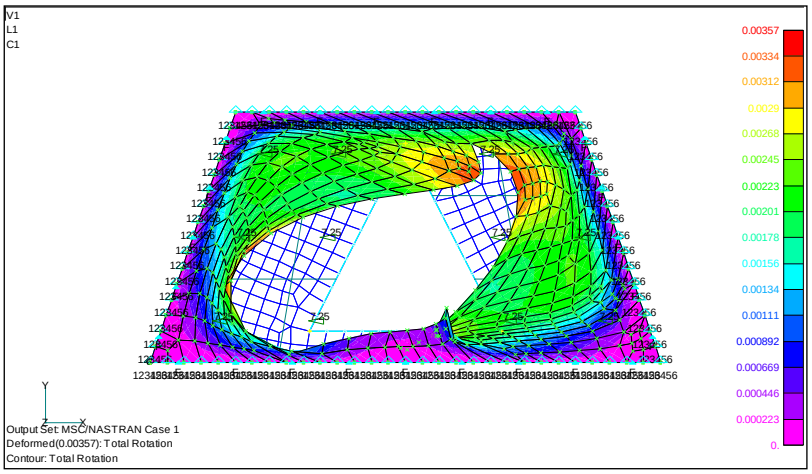

Figure 12. *Rotation Diagram of Skew Plate with Triangular Opening.*

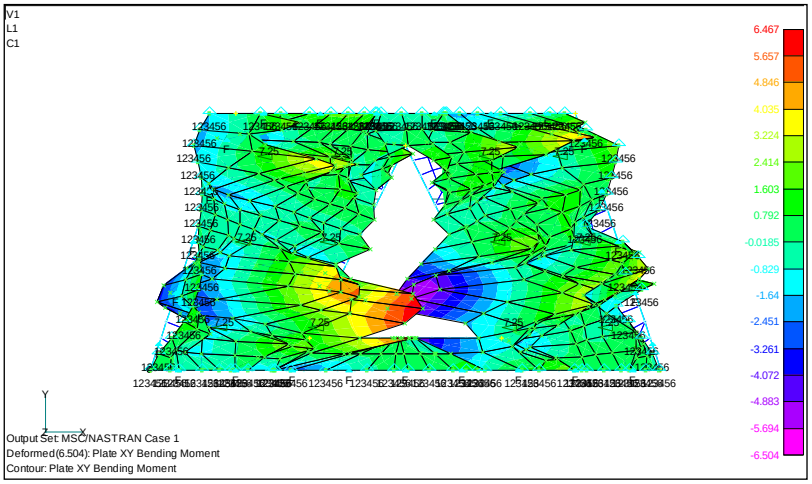

Figure 13. *M_{xy} Diagram of Skew Plate with Triangular Opening.*

4.5. Skew Plate with Trapezoidal Opening Clamped on All Edges

Top width of trapezoidal = 13.9 ft
Base width of trapezoidal = 20.8 ft
Height of trapezoidal = 9.6 ft

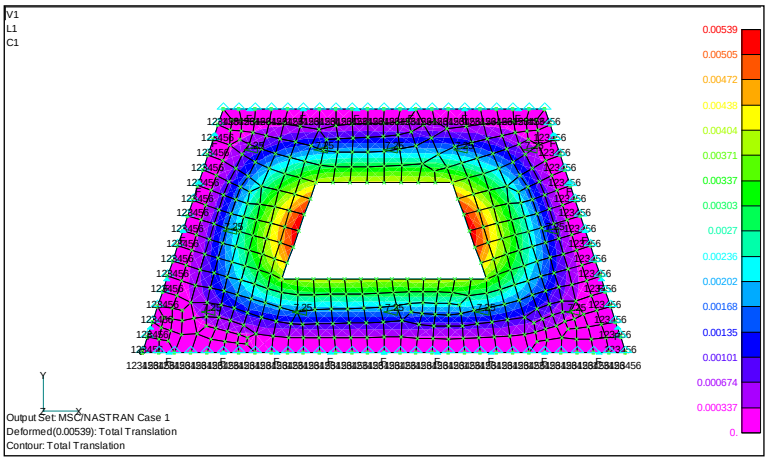

Figure 14. *Deflection Diagram of Skew Plate with Trapezoidal Opening.*

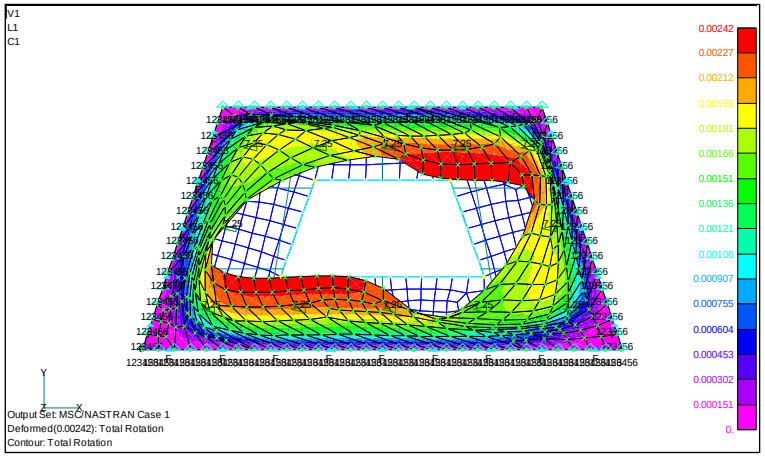

Figure 15. *Rotation Diagram of Skew Plate with Trapezoidal Opening.*

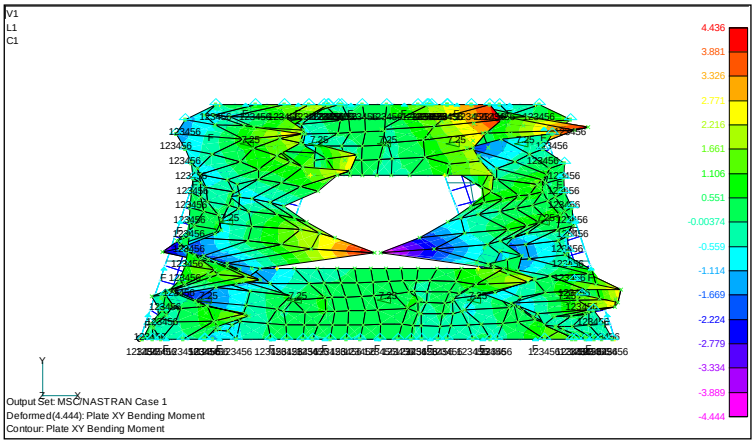

Figure 16. *M_{xy} Diagram of Skew Plate with Trapezoidal Opening.*

4.6. Comparison of Results

The above cases provided us with valuable information. Deflections, rotations, and moments of commonly used openings are shown in Table 1 for comparison purposes.

Table 1. *Comparison of Results.*

Opening	Deflection (in)	Rotation (rad)	Moment (kip-ft)
Circular	0.0056	0.00235	3.85
Square	0.0059	0.00237	3.63
Rectangular	0.00548	0.00232	3.47
Triangular	0.0084	0.00357	6.46
Trapezoidal	0.00539	0.00242	4.44

The results show that in a context of an overall picture, rectangular opening is the best, when compared to other openings. This is because it is susceptible to less deflections, rotations, and moments. The second best is circular opening. Triangular opening generates the highest values of deflections, rotations, and moments.

5. Conclusions

The main goal of this basic work was to evaluate the structural behavior of skew plates with some commonly used openings for a safe design. Five commonly used openings were used for the study, namely: circular, rectangular, square, triangular, and trapezoidal. The structural behavior of the plates is evaluated in the context of deflections, rotations, and moments using MSC Nastran software. The following limited main conclusion was obtained from this work:

In the context of an overall picture, rectangular opening is the best as it produces the least deflections, rotations, and moments.

Future Work

Further research is possible in this basic topic by applying different conditions, materials, and loading type. For example, effects of load on fiber reinforced plastics plates with openings.

Abbreviations

MSC	MacNeal-Schwendler Corporation
$f`_c$	28 Days Compressive Strength of Concrete
μ	Poisson's Ratio
E_c	Concrete Modulus

Conflicts of Interest

The authors declare no conflicts of interest.

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