CURVED STRUCTURE ANALYSIS FOR TYPICAL LOADING WITH RESTRAINED BOUNDARY CONDITION, USING ISOPARAMETRIC BEAM ELEMENT

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ABSTRACT

Analysis of curved structures for different loading patterns and boundary conditions creates complications due to inter-action of in-plane and bending stresses. Due to the availability of fast-running computers, all the complicated structures were now easily analyzed using the Finite Element Method. This paper deals with such types of complicated structures as the Helical staircase, which was not only curved in the plan but also curved in elevation too. Analysis of helical staircase with 90^0 helix angle, 3.6m floor height, and 200mm waist-slab thickness, was carried out for both the restrained support conditions, along with four types of loading pattern. Types of loading were: UDL over entire length; UDL over bottom half-length; UDL over top half-length; Point load at quarter lengths. Using the Finite Element Method Semi-loof beam element was used to analyze the selected staircase. The total staircase was discretized in six equal elements, through 13 nodal points with in-all 72 d.o.f. Results thus obtained for inplane & bending stresses as well as displacements; were plotted and shown in a tubular form also.

KEYWORDS: Boundary Condition - Displacement - Force Resultant, Helix – Isoparametric & Semilo of Beam

1. INTRODUCTION

For any structures, specifically for the curved structures, exact analysis under different loading patterns and support boundary conditions was an essential requirement. For simple and determinate structure, analysis and stress distribution can be very easily and quickly calculated with well-known methods. But in the case of curved structures, exact analysis can only be carried out by special methods, based on fast running computers. It was a well-established fact, that the analysis of curved structures with different boundary conditions and loading patterns creates complications due to the interaction of in-plane and bending stresses. Suitable numerical methods have remarkably gained popularity for analyzing the curved structures with great accuracy, as well as saving huge man-hours, with minimum time consumption. The finite Element Method is selected using an isoperimetric beam element.

Original Article
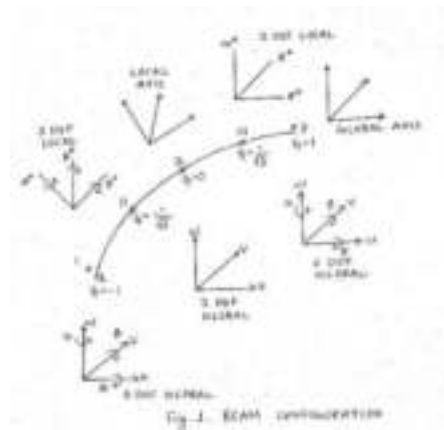
Figure 1: The Basic Nodal Configuration for the Beam Elements was Shown in.

This element hada total of 21 d.o.f. This total of 21 d.o.f. was used to predict axial forces, transverse shears, bending, torsional, values as well as displacements. To analyze the curved structure, a helical staircase of 90^0 helix angles was considered. This curved structure was not the only curve in the plan but it is curved in elevation also. The total helix height i.e., height between the floors was taken as 3.6m. The waist slab thickness was kept 200mm constant throughout. An inner radius was 500 mm, while the outer radius was considered as 1500 mm. The whole staircase was discretized in six equal curved elements. The total number of nodal points was taken as 13 with a total of 72 degrees of freedom.

As support conditions, both top and bottom supports were firmly restrained. The curved structure was analyzed by imposing four types of loading:

- U.D.L. of 5kN/m over an entire length;

- U.D.L. of 5KN/m over bottom three elements i.e., element no. 1, 2, and 3.

- U.D.L. of 5KN/m over the top half of three elements as element no. 4, 5, and 6.

- Similarly, a point load of 1KN was applied at the quarter length of helical stairs from the top as well as from the bottom i.e., at nodes no. 4 and 10.

The displacement, force resultants, and moments resultants in all three directions were calculated and shown graphically. The salient points for maximum values were also shown in a tabular form.

2. METHODOLOGY

The exact stress pattern for the curved structures was complicated. Analysis of these structures was more complicated when applied with various boundary conditions and loading patterns. The analysis of these curved structures as helicord staircase was carried out by using the latest scientific/computer method as Finite Element Method using loof beam element. The whole analysis was carried out to predict displacements, and transverse shears, bending, and torsional moments in all three global directions.

The following parameters were selected

- Helical staircase with total helix angle = 90^0

- Total height of staircase = 3.6 m

- The waist slab thickness = 200 mm

- Inner radius = 500 mm

- Outer radius = 1500 mm

- Area of cross section = 2 x 10^5 mm^2

- Modulus of elasticity, E = 0.12 x 10^5 N/mm^2

- Modulus of rigidity, G = 0.52173 x 10^4 N/mm^2

- Moment of Inertia, I_{zz} = 66.66 x 10^5 mm^4

- Moment of Inertia, I_{yy} = 16.66 x 10^9 mm^4

- Polar moment of Inertia, I_p = 2.288 x 10^8 mm^4

- Unit weight of R.C.C. = 24 KN/m^3

- Poisson's Ratio, μ = 0.15

The whole structure was discretized in six equal elements.

Total no. of d.o.f. = 72

Total no. of nodal points = 13

Boundary conditions: both top and bottom supports were restrained completely.

Load cases: a total of four types of loads were taken into considerations for the analysis of the helical staircase.

Case 1: a uniformly distributed load of 5 KN/m over the entire span length i.e., over a total of six elements.

Case 2: a uniformly distributed load of 5 KN/m over the bottom half-length of total span i.e., over element no. 1, 2 and 3.

Case 3: uniformly distributed load of 5 KN/m over the top half-length of total span i.e., over an element no. 4, 5, and 6.

Case 4: point load of 1 KN at each quarter length from the bottom & top supports. i.e., node no. 4 and no. 10

3. OBSERVATION

The whole curved helical with 90^0 helix angles was analyzed, using a computer program with different required sub-routines. The parameters thus obtained for all the four loading cases, mentioned above, as well as for top & bottom supports in restrained conditions, were shown graphically as well as in a tabular form to assess the conclusion.
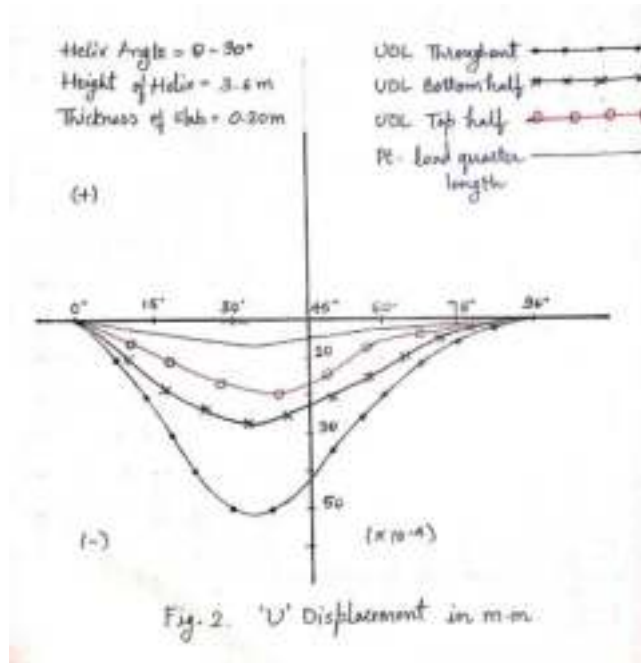
Figure 2: The Displacement in 'U' Direction in mm, over the Entire Length of the
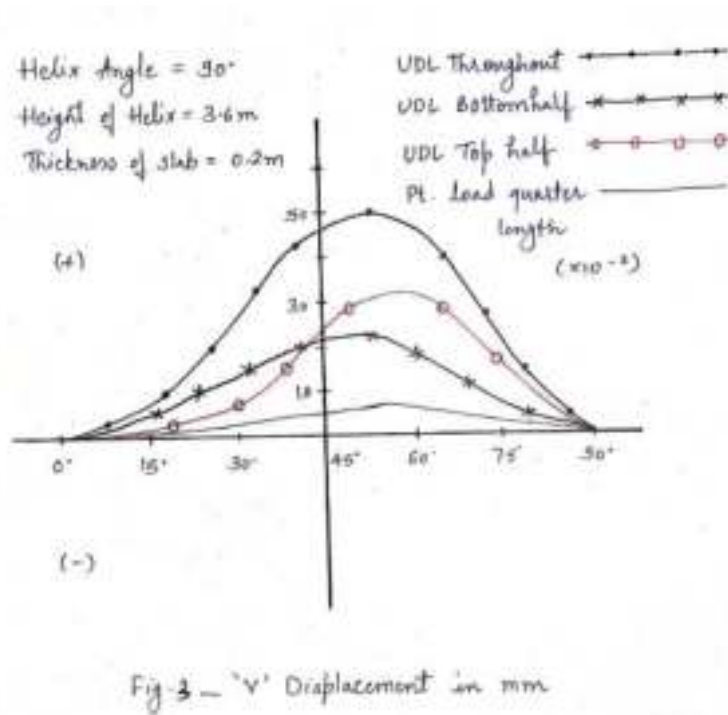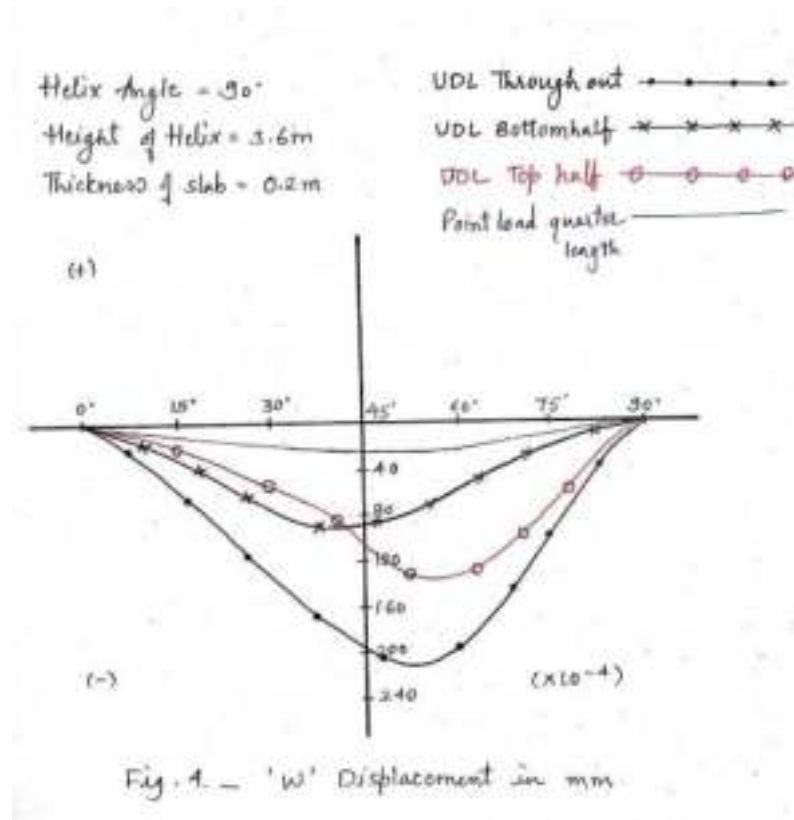Structure, with four Loadings, was Shown in.

Figure 3: Similarly for all the Four Types of Loads Applied to Predict the
'V' Displacement in mm Graphically shown in.

Fig. 4 — 'W' Displacement in mm

- The displacement in 'W' direction in mm, to analyze the curved helicoid staircase for all the four types of loading were predicted and shown graphically in Figure 4


Fig. 5 'Fx' Force Resultant in kn
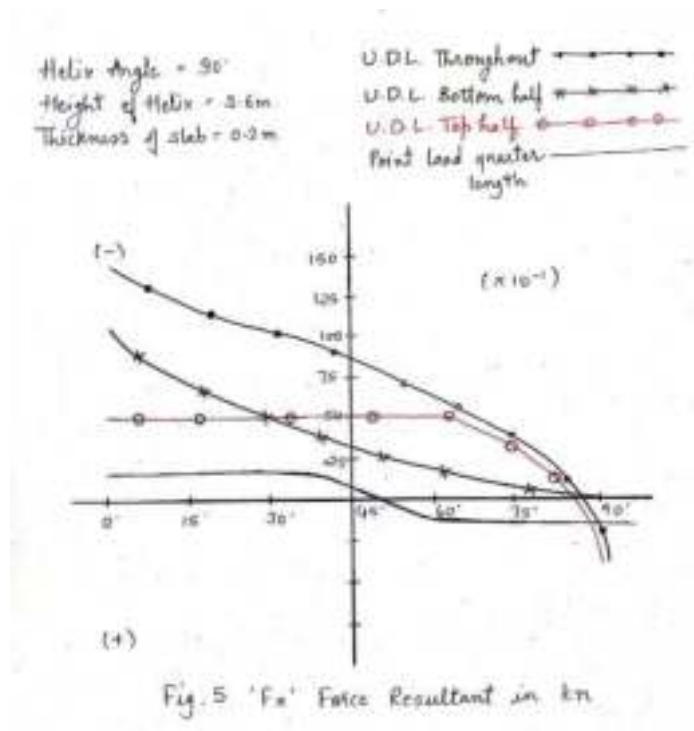
- The force resultant "F_x" in KN was predicted for all the four types of loading, mention above, were graphically

displayed in Figure. 5


Fig. 6 - "Fxy Force Resultant in tM
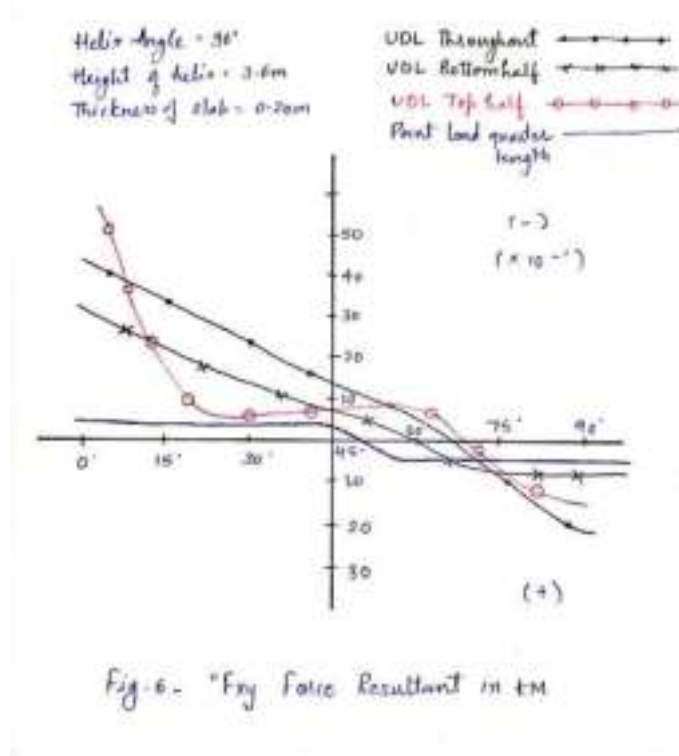
- The force resultant "F_{xy}" in KN were obtained for U.D.L. over the top half-length of the staircase and point load, applied at quarter length from the top as well as from bottom; and displayed graphically in Fig. 6


Fig. 7 - 'Fxz' Force Resultant in kN
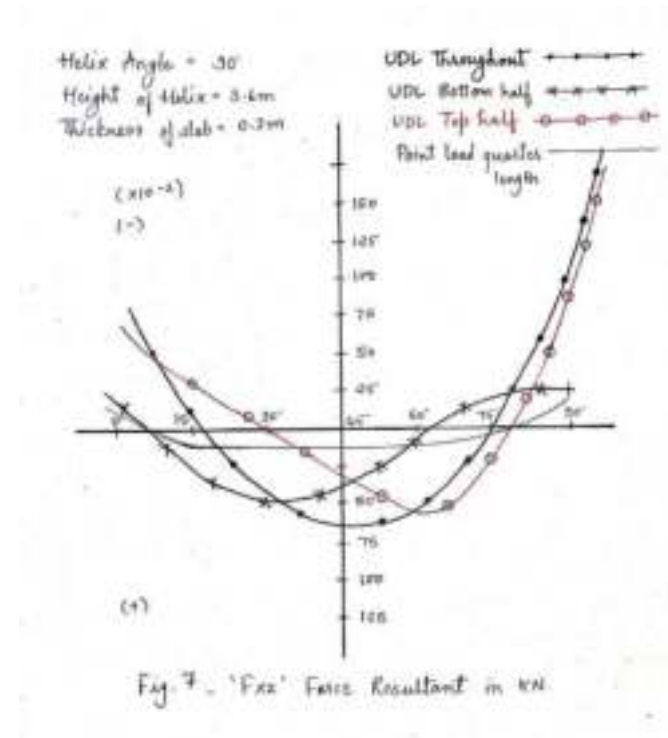
- Similarly, the force resultant "F_{xz}" in KN was obtained for full-length U.D.L. over element no. 1 to element no. 6.

In addition to the above loading, other remaining three loadings were applied and the result thus obtained were plotted and displayed in Figure. 7

Fig 8 – "Mxy" Moment Resultant in KnM
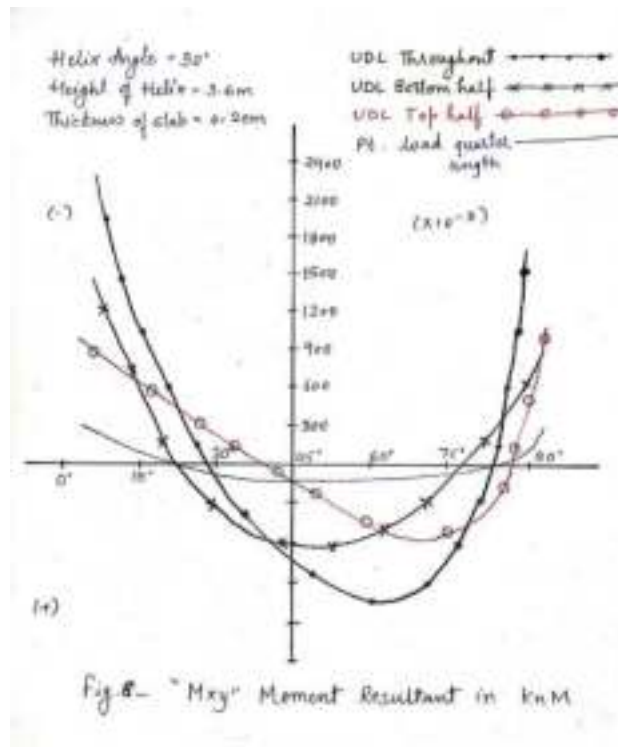
- Moment Resultants: The moment resultant "M_{xy}" in KN-M for the typical four loadings applied to the helical staircase was plotted and shown graphically in Figure. 8

Fig 9 – "Mx2" Moment Resultant in Kn M
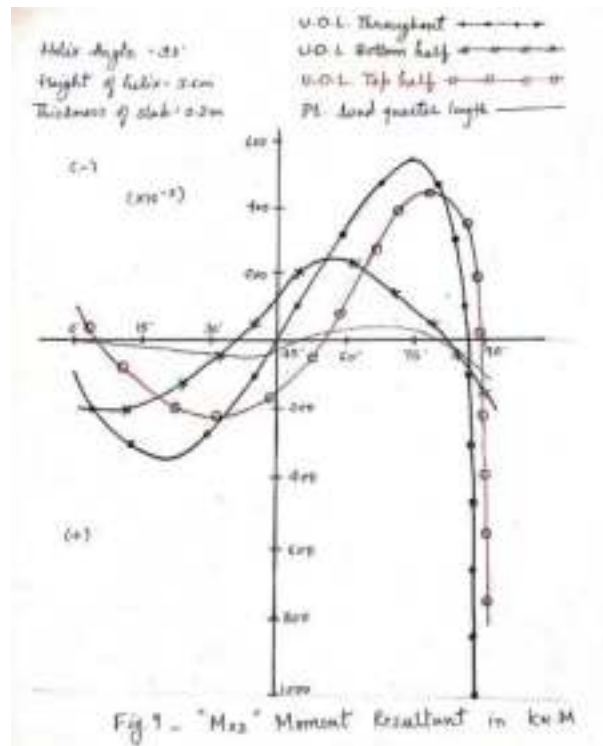
- The moment resultant "M_{xz}" in KN-M were obtained after analyzing the curved helical structure for restrained boundary conditions & other four types of loading, already mentioned above, were shown graphically in Figure. 9

Fig. 10. "TOR" Moment Resultant in KNM.
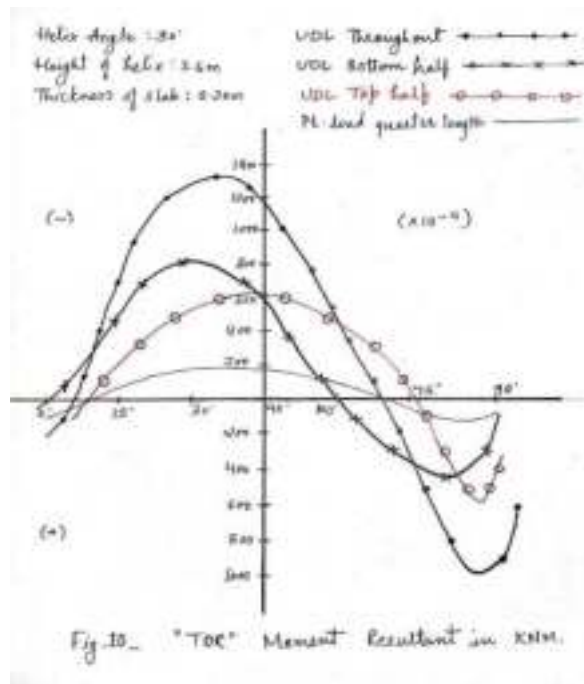
- The torsional moment resultant "TOR" in KN-M was plotted for restrained boundary conditions and well-selected four types of loading, in Figure. 10

- The salient value for nodal displacements for U, V & W directions were shown in table 1

Table 1: Showing Displacement in MM

S.No.	TYPES OF LOAD	'U'	'V'	'V'
1	UDL Throughout	50×10^{-4}	50×10^{-3}	50×10^{-4}
2	UDL Bottom half	30×10^{-4}	21×10^{-3}	86×10^{-4}
3	UDL Top half	21×10^{-4}	31×10^{-3}	140×10^{-4}
4	Point load quarter length	5×10^{-4}	5×10^{-3}	23×10^{-4}

- The salient values of stress resultants F_x, F_{xy} & F_{xz} were displayed in Table 2

Table 2: Showing Force Resultant in KN

S. No.	Types of Load	'F_x'	'F_{xy}'	'F_{xz}'
1	UDL Throughout	135×10^{-1}	40×10^{-1}	240×10^{-2}
2	UDL Bottom half	85.5×10^{-4}	30×10^{-1}	23×10^{-2}
3	UDL Top half	50×10^{-4}	96×10^{-1}	220×10^{-2}
4	Point load quarter length	14×10^{-4}	4×10^{-1}	27×10^{-2}

- The salient values for moment resultants as "M_{xy}, M_{xz}, TOR, were displayed in a tabular form in Table 3

Table 3: Showing Moment Resultant in KN-M

S.No.	Types of Load	'M_{xy}'	'M_{xz}'	'TOR'
1	UDL Throughout	2400×10^{-1}	990×10^{-3}	1300×10^{-4}
2	UDL Bottom half	1500×10^{-4}	220×10^{-3}	800×10^{-4}
3	UDL Top half	950×10^{-4}	780×10^{-3}	660×10^{-4}
4	Point load quarter length	280×10^{-4}	130×10^{-3}	150×10^{-4}

4. CONCLUSIONS

- The maximum displacement in the "U" direction is 15^0 from the center of the span, towards the bottom support.

- Displacement "V" direction for all the four selected load cases, it was observed that the maximum displacement in 15^0 from the center of the span, towards the top support.

- Maximum "W" displacement for the selected loading condition is maximum, 15^0 from the center of the staircase towards the top support.

- The maximum value of force resultant "F_x" & "F_y" is maximum at bottom support only.

- The value of force resultant "F_{xz}" was observed to be maximum at the top support of the helix staircase.

- Effect of selected loadings for moment resultant "M_{xy}" was observed to be maximum

- The effect of "TOR" (Torsional Moment Resultant) is the bare minimum and behaves like a sinusoidal wave.

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