An Analytical Study on Slipforming of Vertical Concrete Structures

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Abstract- Slipforming techniques perform better for circular concrete structures than the rectangular structures. More issues such as lump formation, lifting cracks were observed while constructing a rectangular shaped vertical structure using slipform. Few studies on workability, setting time and hardening of concrete, friction, bonding between slipform and concrete are found in literature to address the issues. In this paper the issue due to deformation of formwork during construction and lifting has been attempted. While pouring the concrete between the panels, the concrete exerts pressure on the panel and the panel gets deformed. Deformation in the panel due to the lateral pressure by fresh concrete is studied by varying the length of the longer side of the panel. After placing and enough hardening of concrete, the slipform gets lifted vertically. Damages in the concrete are expected to happen due to the deformation in the formwork caused by the pressure acting on it which results in the pinching of concrete. In order to analyze this problem, the finite element analysis package ANSYS software is used to determine the deformation of the panel.

Keywords- slipforming; friction; finite element analysis; pressure; deformation

I. Introduction

Slip forming is a construction technique that facilitates concrete structures without any horizontal construction joints. This construction technique has been used for several decades for production of concrete structures [4]. Different types of structures are slip formed, but typical ones are vertical structures such as towers, bridge columns and offshore platforms [3]. Slip forming is not only used for straight vertical structures, but also on structures where geometry of the structures and wall thickness is changed. Slip forming is normally a continuous working operation, which requires well-planned supply of materials, presence of personnel at all the time. Slip forming is labour intensive over short periods but when properly planned and executed, it offers significant advantages with respect to overall construction time, quality and safety. This method has made great progress during the past decades, particularly in relation to the large concrete platforms and storage tanks delivered to the oil and gas industry and for tall concrete buildings, chimneys and pylons [3, 6].

This method of construction was developed in Canada about 100 years ago, from a technique devised by late Mr J.S. Metoalf in 1900 for building a silo of four small bins. This silo is still in use, and the plans for its construction have been preserved. A few decades later, for the first time, a wooden rising form using wooden screw jacks and wooden yokes was operated, and six years later, in Tennessee, the first apartment building was constructed using slip forming (Ratary 1980). In 1974, the slip-form method was used to construct the concrete shaft of the CN tower in Toronto, with 345 m height in 8 months [10, 14, and 15].

Slip forming is a highly efficient method of constructing long pavements and tall concrete structures. Rate of construction of several meters per day of varying geometrical shapes and cross sections, containing multiple inserts and openings can be achieved within strict geometrical tolerances.

The rest of this paper is organized as follows. Section II discusses issues during slipform. Section III gives analytical studies. Section IV provides an Analytical solution for deformation of the panel. Finally, a brief conclusion of the work is presented in section IV.

II. Slipform Issues

Slipform techniques consists of forming panels, walors, yokes, jacks and jack rod, work or storage decks and scaffolding, etc., [2]

Types of Slip Forming:

- Horizontal construction
- Vertical construction

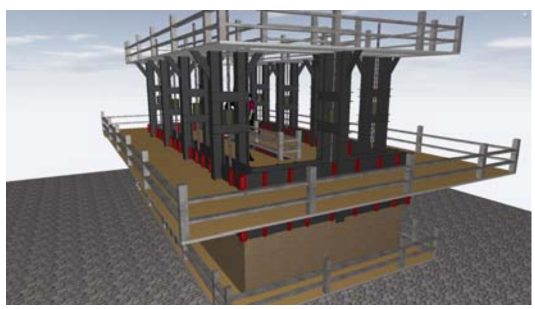
Horizontal Construction:

It is a process which is used to consolidate, form into geometric shape finish a Plain Cement Concrete (PCC) mass by pulling the forms continuously through and surrounding plastic concrete mass.

Appropriate for larger jobs that require high production rates.

Vertical Construction:

In vertical slip forms concrete is continuously placed, compacted, and formwork is pulled up. Rate of slipping of formwork depends upon the temperature and strength development of concrete. This method is suitable for uniform shaped structures. The formwork rises continuously, at a rate of about 300 mm per hour. The formwork system has the three platforms as upper, middle and lowers [11].



It is used for rapid construction. The literature deals with the cause of the defects. However many types of damages have been found during slipforming. Surface damages have occurred during slip forming. Typical surface damages are lifting cracks and vertical lined damages caused by lumps formed on the slip form panel [8].

Problems noted (lifting & sliding stress):

The lifting stress can be divided in static lifting stress and sliding lifting stress, where the static lifting stress represents the friction that has to be overcome in order to start sliding and the sliding lifting stress is the minimum friction that occurs during sliding. Both the lifting frequency and the lifting height had a considerable effect on the static lifting stress. Lower lifting height or decreased lifting frequency will both result in a higher static lifting stress [8].

1. Surface defects:

The worst result on the hardened structure during slip forming is the development of damages caused by movement of the slip form panel. Any damage initiated during the period from the concrete has lost the workability to the slip form panel is detached from the concrete. It is also in this period the concrete strain capacity is low.

1.1 Lifting cracks:

Horizontal (long) cracks on the wall face perpendicular to the lifting direction are normally lifting cracks. The depth and width of these cracks may vary from thin and shallow to deep and wide. Lifting cracks are associated with forces during lifting of the slip form panel. Shaking or vibration of the slip form can also make cracks. Lifting cracks that occur during slip forming has often been assumed to be the main cause for the poor concrete quality for some slip formed concrete structures.

1.2 Delamination:

Delamination of the concrete in the cover zone is concrete separated or displaced from the substrate. A vertical crack in the cover zone parallel to the reinforcement, and sometimes invisible on the surface, is delamination of concrete. Delamination is also areas where the concrete in the cover zone is lifted together with the panel and makes the cover deficiency on the wall face clearly visible.

1.3 Lump formation:

Lump formation starts as a thin layer of grout sticking to the form panel. It continues to grow layer by layer until a lump is formed. After the lump hardens it continues to grow horizontally and vertically. A lump can after a while easily be seen on the wall when the fresh concrete in the cover zone is pushed up during lifting and a clear visible cover deficiency is made.

1.4 Concrete collapse:

Backsliding of concrete or concrete collapses happen when the slip form panel does not support the concrete any longer and the concrete strength is too low to carry its own weight.

III. ANALYTICAL WORK – AN OVERVIEW

The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. In this method of analysis, a complex region defining a continuum is discretized into simple geometric shapes called finite elements. The material properties and the governing relationships are considered over these elements and expressed in terms of unknown values at element nodes. An assembly process, duly considering the loading and constraints of result in a set of equations. Solution of this equation gives us the approximate behaviour of the continuum.

A. Validation of ANSYS:

In order to validate the ANSYS software, a cantilever beam and a plate has been modelled and analysed with finite element type`SOLSH190' of 3D 8 node structural solid shell.

Cantilever beam is modelled and analysed with the following details given below.

Length of the beam: 4m, Depth of the beam=0.5m,

Breadth of the beam = 0.2m and uniformly distributed load of 2000 kN/m^2 is given on the top surface of the beam.

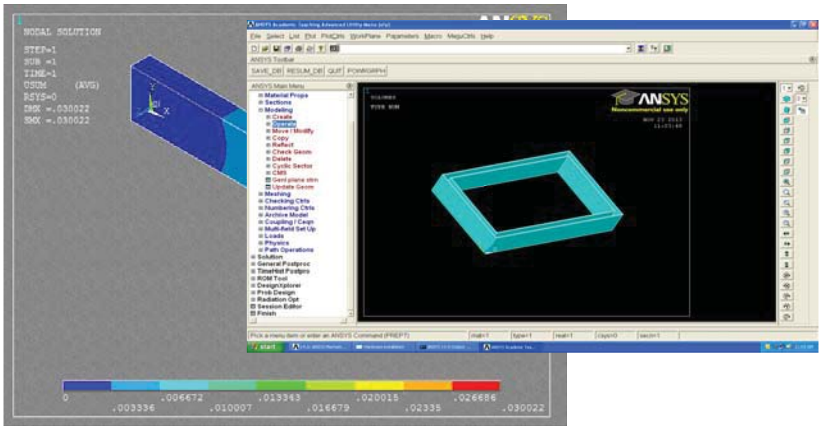


Fig.1 Deformation of Cantilever Beam

From Fig.1, The maximum deflection at tip obtained from ANSYS analysis is 30.02mm and when it is calculated manually using the theory of elasticity equation it comes around 30.7mm leaving percentage of error to 2.27%.

Now the plate is modelled as shown below in Fig.2. Detail of the plate is given below.

Length of the Plate: 2m, breadth of the plate= 4m,

Thickness= 5mm, uniformly distributed load of 2000 kN/m^2 is given on the top surface of the beam.

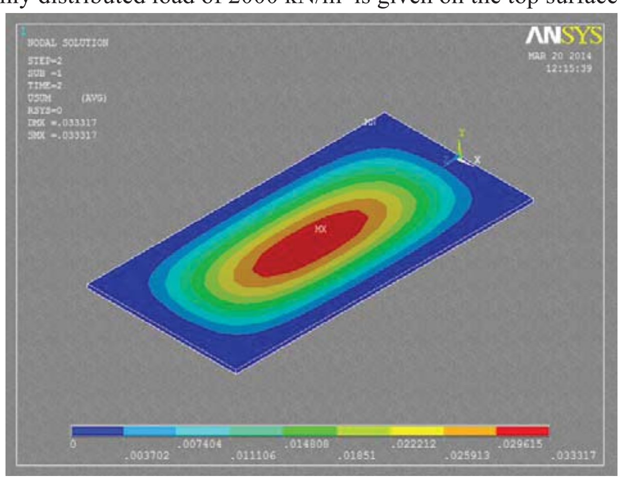


Fig.2 Deformation of plate

From Fig.2, the maximum deflection at mid point is 34.4mm and when it is calculated manually using the theory of elasticity equation; it is 35.5mm leaving percentage of error to 3.1%.

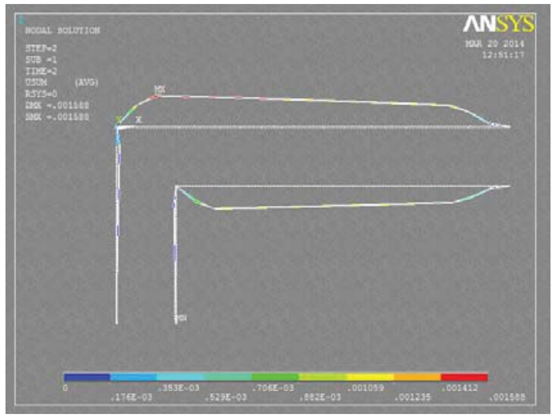
With this validation, real problem has been taken for analysis with ANSYS. Similarly the rectangular slipform with inner and outer panels have been modelled.

B. Modelling of Slipform panel:

Slipform panel is modelled as shown below in Fig.3. The details of the slipform panel are as given below:

Height of the Panels: 1m, Thickness of the panel= 5mm,

Wall thickness= 0.3m, length of the shorter side is fixed as 2m and length of the longer side is varied for the aspect ratios.



Since the rectangular box is symmetrical , a quarter portion of it has been taken for analysis.

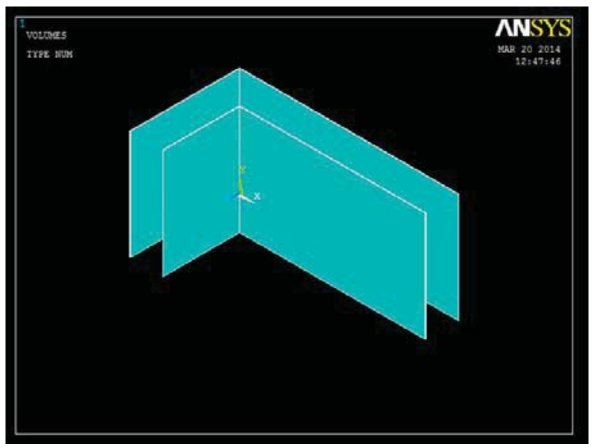


Fig.4 Deformation of Slipform panel

C. Deformation of slipform panel:

Slipform panel were modelled as shown in Fig.4 and uniform pressure of 25kN/m^2 was distributed on both the panels from inner side of the panel to the Aspect ratio 2.

The maximum deformation at longer side outer panel is 1.588 mm. It is noted from Fig.4 that longer side moves out and shorter side comes in and rigid joint maintains its 90° angle.

IV. ANALYTICAL RESULTS

Details of Slipform panel for various aspect ratio

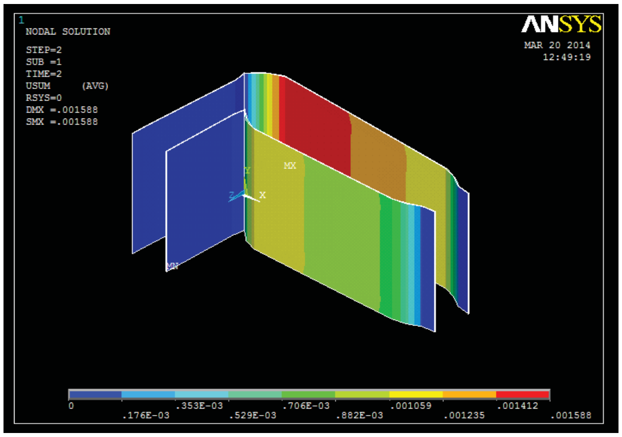
The slipform panel has been modelled in ANSYS and analysed with finite element type `SOLSH190' for various aspect ratio.

TABLE I: DETAILS OF SLIP FORMWORK MODELS

Aspec Ratio	Length of the panel Shorter side (n	Longer side(m)	Height of t panel(m)	Thickness o the panel (mm)	Lateral Load applied (N/m^2)
1	2	2	1	5	25000
2	2	4	1	5	25000
4	2	8	1	5	25000
8	2	16	1	5	25000

Deformation pattern of the slipform panel:

Along the depth, the deformation pattern of both shorter and longer panel has been noted as shown in Fig.5 & 6. The deflection pattern for a uniform pressure, where we can notice that the deflection of the longer side increases along the depth with the maximum at the bottom (since maximum load is at the bottom). On the other hand the shorter side seems to possess a pattern as that of a uniformly distributed load.



The above figure shows the deformed shape of the panel both inner and outer side with enlarged scale.

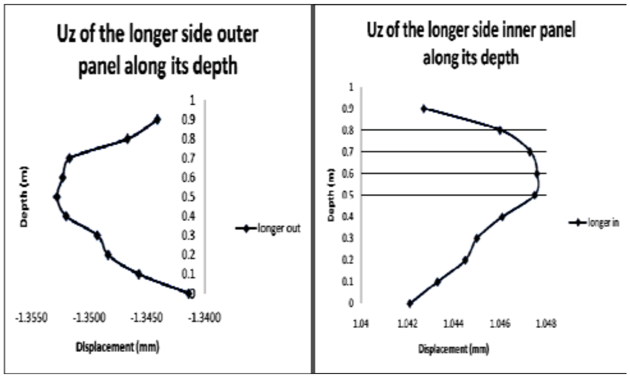


Fig.5 Uz of a longer side panels along its depth

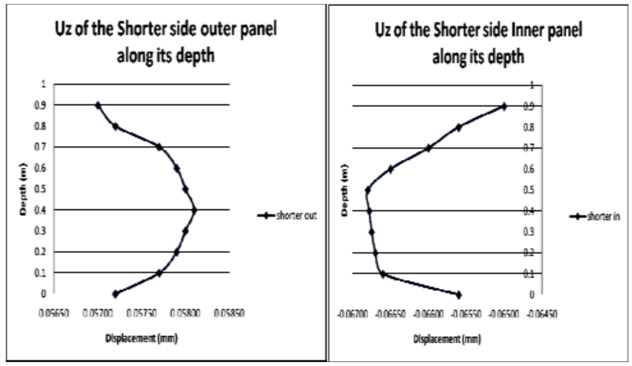


Fig.6 Ux of a shorter side panels along its depth

Keeping the above results in view, we decided to do further analysis for different aspect ratios in order to check the influence of the longer side with respect to the shorter side.

Combined deflection pattern of panels:

Fig.7 & 8 shows the combined deflection pattern of outer & inner panel of a longer side. Here too, we can note the displacement is so larger for aspect ratio-8 then that of other ratio.

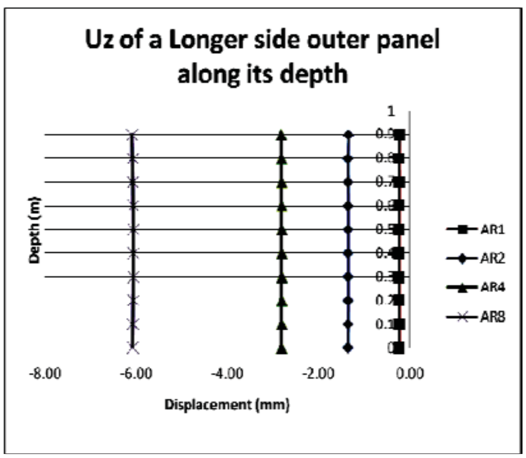


Fig.7 Combined deflection pattern of longer side outer panel

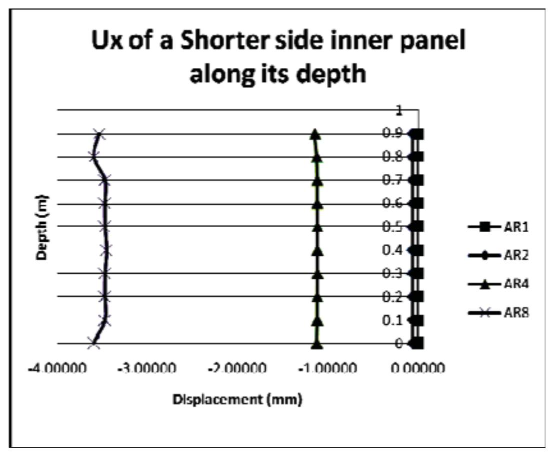


Fig.9 Combined deflection pattern of shorter side outer panel

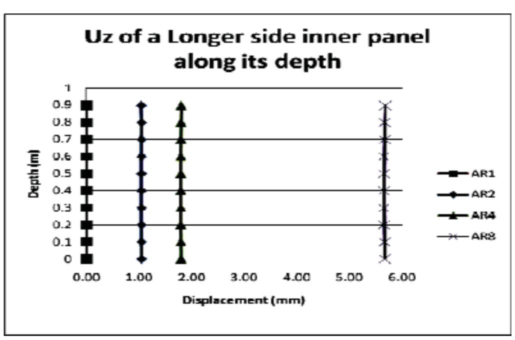


Fig.8 Combined deflection pattern of longer side inner panel

Fig.9 & 10 shows the combined deflection pattern of outer & inner panel of a shorter side. Here too we can note that the displacement is so larger for aspect ratio-8 then that of other ratio.

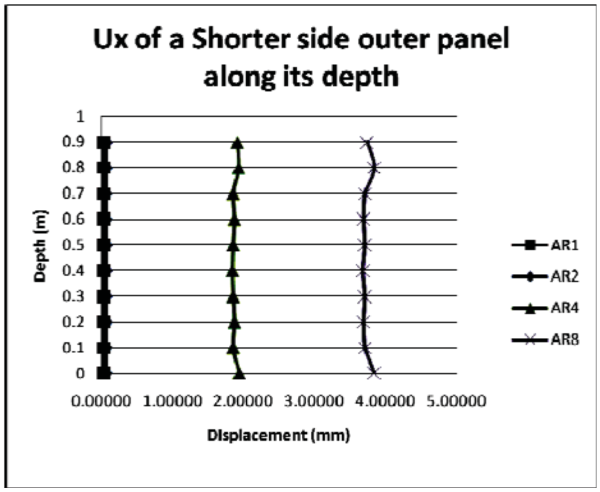


Fig.10 Combined deflection pattern of shorter side inner panel

Results and Discussion:

The formwork deformation obtained from analysis, generally tend to deflect outward at mid height compared to top and bottom. So lump formation will happen from the bottom of the slipform mainly at mid distance from corner and jack.

Lump formation can be reduced first by placing the jacks at equidistance on both the sides from the corner. Then to reduce the deformation stiffeners are provided on the shorter side as well as the longer side. Other than the stiffeners, providing intermediate supports to the panels decreases the deflection. Intermediates supports may be given by angles. It will be provided at every 5m to 6m, by which the thickness of the panels also can be reduced. Once the slipform is designed properly with stiffeners, deflection will be reduced thereby pinching of concrete shall be reduced.

V. CONCLUSION

This paper is specifically concerned about investigation of a rectangular slip form which is modelled and analysed for different aspect ratios by finite element analysis using "ANSYS" software.

The modelling of the slip form was done using solid shell element type with 8 node. On analysing the slip form, the deflection patterns for both shorter and longer side has been obtained. It clearly indicates that the longer edge of the slip form moves outer side and shorter side comes in. It is noted that deflection pattern of the shorter side along the depth actually causes the pinching of concrete and thereby leads to damage of the structure throughout the height. On further study, pinching can be controlled by providing stiffeners throughout the slip form. When aspect ratio is 1, deformation is uniform along height. So it is recommended to place the jacks on both walls at equidistance from corner. Thus proper designing of slip form is needed in order to reduce such damage.

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