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Experimental Investigation of Lateral Pressure on Vertical Formwork Systems using Self Compacting Concrete

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Abstract— The modeling of pressure distribution of fresh concrete poured in vertical formwork are rather dynamic than complex. Many researchers had worked on the pressure distribution modeling of concrete and formulated empirical relationship factors like formwork height, rate of pour, consistency classes of concrete. However, in the current scenario, most of high rise construction uses self compacting concrete(SCC) which is a special concrete which utilizes not only mineral and chemical admixtures but also varied aggregate proportions and hence modeling pressure distribution of SCC over other concrete in vertical formwork systems is necessitated. This research seeks to bridge the gap between the theoretical formulation of pressure distribution with the actual modeled (scaled) vertical formwork systems. The pressure distribution of SCC in the laboratory will be determined using pressure sensors, modeled and analyzed.

Index Terms— Formwork Systems, Hardening of Concrete, Lateral Pressure, Piezoelectric sensors, Self Compacting Concrete..

1 INTRODUCTION

In general, Formwork plays a crucial role in construction industry on both economy and time of execution. With the influence of technology and improvements in construction activities, expectation of completion of any project irrespective of volume and size, long life serviceability and safety is required with uninterrupted progress. SCC, being expensive to Ordinary Portland cement (OPC) needs perfect formwork fixtures and alignment which recommends the aluminium and steel formwork systems compared to conventional (timber) formwork system. At present times, every work simplified to complete in less time and proper execution with high quality standards. Self Compacting Concrete (SCC) exhibits more liquidity content which is similar to water on its flow making the formwork erection more significant and careful handling from pouring of concrete through hardening time.

On account of economy and investment for any construction project, formwork panels and other erection equipments cost 60% of total project cost. So proper planning for selection of formwork panels from initial work of concreting towards completion has to be done without the risk of failures in handling and installation of panels with alignment props. Repetitive usage of formwork components is highly recommended to avoid high stake of money investment. With the use of SCC, hydrostatic pressure all along the verticality are to be considered higher and maximum pressure exerted are to be calculated for positioning of alignment props are placed if required. Formwork pressure is influenced by concrete height, casting of concrete and method, maximum aggregate size, rheology of fresh concrete, setting time, formwork shape and admixtures used.

Ahmed A. Abouhussien and Assem A. A. Hassan [1] gave the brief procedure of mix design for high strength SCC with various % of metakaolin through numerous trials on statistical analysis datum. L. Ruiz-Ripoll, S. P. Shah, B. E. Barragan and J. Turmo [2], derived the impact of mix design of SCC with initial testing properties and interferences by the same over formwork pressure from fresh stages of concrete.

Ahmed F. Omran and Kamal H. Khayat [3], gave the idea on measurement on lateral pressure from deflection of formwork using strain gauges and Sherbrooke pressure device and major parameters which affect the formwork pressure as effect of Slump flow, rate of casting, VMA and HRWRA contents with effective water/ cementious material ratio and size of aggregate. Seung Hee Kwon, Quoc Tri Phung, Hong Yong Park, Jae Hong Kim, Surendra P. Shah [4], exhibited the lateral pressure with and without friction effect on formwork using mortar and SCC.

Mark Talesnick and Amnon Katz [5] listed the various methods of monitoring lateral concrete pressure over time considering the sensor deflection and particle size distribution of fine aggregate in concrete. A. Perrot, S. Amziane , G. Ovarlez, N. Roussel [6], presented the idea of inducing steel rebars in SCC and their lateral pressure is recorded proportional to vertical stress induced by fresh concrete.

In this present paper, a study on lateral pressure of SCC on formwork systems using piezoelectric sensors is carried out over normal and congested reinforcement rebars which helps for formwork verticality and alignment prop positioning.

2 SENSOR WORKING PRINCIPLE

Piezoelectric sensor works on Newton’s third law of motion, stating that the load which imposed on the sensor is directly proportional to voltage exhibited onto its terminals. White dial on the sensor connected from the core part of the sensor which acts the respond medium to take up the load is fused as positive terminal.

Brown layer outside the white dial acts as the negative terminal as shown in Fig. 1. These two wires are connected to multimeter which records the voltage against the load with respect to time. If these sensors are connected in series as in Fig. 2, acts as a single system of sensor giving corresponding loads all along its running length. Sensors can be placed at any point on the formwork panel, concrete self weight on it gives the voltage as output at that instant and at that respective time. Proper attention and care is needed while binding the wires to sensors and attaching the sensors towards the formwork frame such that sensors should not short circuit.

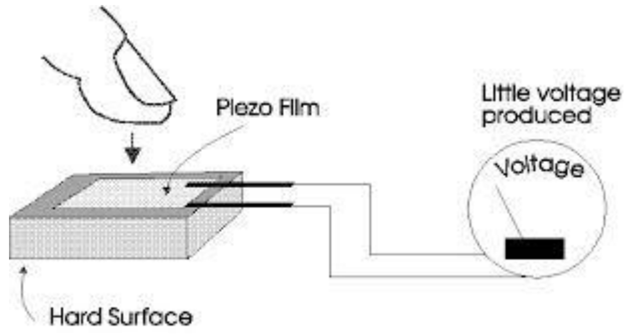

Fig. 1. Piezoelectric Sensor Working Principle

Fig. 2. Sensors in Series

3 Analysis of Formwork Pressure

As per CIRIA Report 108, Formwork pressure exerted can be calculated based on location and quantity of concreting being done, Maximum Conrete Pressure,

$P_{max}=D[C_1(R)^{1/2} + C_2K ((H-C_1(R)^{1/2})1/2]$ or Dh KN/m^3

C_1–Coefficient values dependent on size and shape of formwork, $mh^{1/2}$

C_2 - Coefficient values dependent on materials of Concrete, $m^{1/2}$

D - Density of Concrete, KN /m^3

H - Vertical Form Height, m

h - Vertical pour height, m

K - Temperature coefficient = $(36/ T+16)^2$

R - Rate of rise, m

T - Concrete temperature at placing, ^oC

Value of Coefficeint C_1 and C_2

For Walls: C_1=1.0

For Columns: C_1= 1.5, SCC Concrete C_2 =0.6

For Column, Pmax = 25[1.5*(3.2)1/2 + 0.6* (0.84) (1.57)] or 25* 3 =75 KN/m^3

= 25[2.68+.4] = 77 KN/m^3 or 75KN/m^3

Max Pressure from top = Column Pressure / Density of Concrete = 75/25= 3m

For Walls, Pmax=25[1.0*(3.2)1/2+ 0.6 * (.67 *(0.8)(.45)] - =48KN/m3 or 75 KN/m3

Max Pressure from top = Column Pressure / Density of Concrete = 48/25= 1.92m

3.1 Analysis of Column Formwork

Uniformly varying load =75KN/m^2*0.3m =22.5 KN/m.

Stiffeners are placed all along frame edges to restrain moment overturn at the base from 0.25m, 0.65m, 1m respectively.

Reactions from the UDL are calculated as R_a=26 KN, R_b=28KN, R_c=10 KN.

Max. Reaction /Spacing of Stiffener= 28KN/0.4m=11.2KN/m for every stiffener restrained from the base.

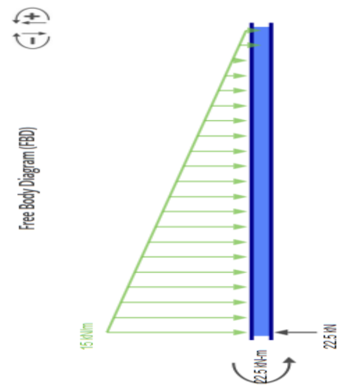

Fig. 3. Column Pressure Distribution

3.2 Analysis of Wall Formwork

Uniformly distributed load= 48KN/m^2 * 0.2m= 9.6 KN/m.

Horizontal Stiffeners (Wales) are placed along the frame edges to restrain moment overturn from the base at 0.20m, 0.60m, 1m respectively.

Reactions from the UDL are calculated as R_a= 32 KN, R_b= 45KN, R_c=20KN. Vertical Stiffeners (Struts) are placed for exceeding Reactions >20KN and 1 vertical stiffener is needed to arrest the expansion along the vertical face of formwork panel. Single pour of concrete may require to restraint the frame from expansive on fresh free flow concrete.

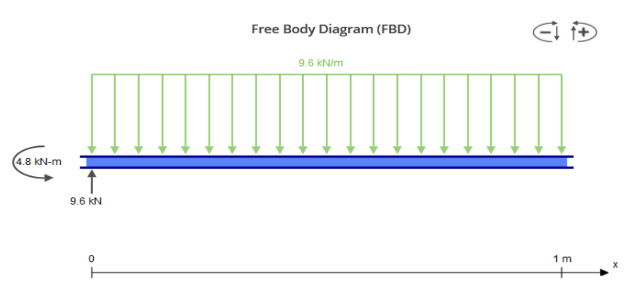

Fig. 4. Wall Pressure Distribution

ns such as rate of rise, concrete volume and concrete height varying in formwork methods and materials with risk in handling and installations. In this research, steel formwork is selected based on economy and volume of work with repeatability. From the Table 1, the selection of formwork panel thickness can be done by calculating the maximum formwork pressure exerted.

4.2 Equal Angles

Panels are made rigid with the stiffening angles at the faces of the frame to support the concrete load and maintain verticality with help of alignment props if needed at the execution. Based on maximum concrete pressure, formwork panel thickness running throughout its length all along the height is restricted to 3mm. Stiffeners can be flat

TABLE 1
FORMWORK PRESSURE VS PANEL THICKNESS

MAXIMUM CONCRETE PRESSURE (KN/M^2)	PANEL THICKNESS
25 TO 40	1.5 mm
40 TO 60	2 mm
60 TO 90	3 mm

TABLE 2
SCC PRELIMINARY TESTS

TESTS PERFORMED	OBSERVED DATA	SCC REQUIREMENT
Slump flow	650 mm	600- 700 mm
T 500	6 secs	5-8 secs
Compaction Factor Test	0.96	0.9-1

tie or angle sections based on position and loading frame as in Fig. 5, Equal Angle Section 35*35*6 mm is selected as stiffeners all around the formwork panel. Properties of equal angles 35*35*6mm are,
Sectional Area=386 mm^2.
Weight/meter =35N
$Iz=Iy=4.1*10^4 mm^4$.
$Iu=6.5*10^4 mm^4$.
$Iv=1.7*10^4 mm^4$.
$Zez=Zey=1.7*10^3\ mm^3$.
Kl/r_v=1000/6.7=149.25 Yield Stress, fy=250 MPa.
f_{cd}=60MPa. (Column Buckling Class ‘c’)
Total Load Capacity= Fcd*area=60*386=23.16KN>20KN.
OPC 53 grade (Class-F)
Specific Gravity of Cement=3.15
Specific Gravity of CA=2.74
Specific Gravity of FA=2.68
W/c ratio=0.40

Fig. 5.Framework with Angle Sections

5 MIX DESIGN

Cement used:
OPC 53 grade (Class-F)
Specific Gravity of Cement=3.15
Specific Gravity of CA=2.74
Specific Gravity of FA=2.68
W/c ratio=0.40
Water to be used (20mm coarse aggregate)=186 litres.
Superplasticiser, Conplast=3% weight of water.
VMA, Master Matrix =2% weight of water.
AEA, Micro air =.5% weight of water.
Max. Cement content=180/.43=420 Kg/m3 > 350Kg/m3.
Volume of Coarse Aggregate/Total Volume of agg=0.64.
Volume of Concrete=1 m3.
Volume of cement=350/(3.15*1000)=.11m3.
Volume of Water=180/1000=.18m3.
Volume of Coarse Aggregate=1-[.11+.18]=.71m3.
Mass of Coarse Aggregate=$\%CA*SG_{ca}*V_{agg}*1000$
= .64*2.74*.71*1000= 1245Kg.
Mass of Fine Aggregate = $\%FA*SG_{fa}*V_{agg}*1000$
= .36*2.68*.71*1000= 685Kg.
$V_{cement}: V_{water}: V_{fa}: V_{ca}=420:180:685:1245$
$=1: .43: 1.631: 2.96$
VMA=2%Vwater=8.4 litres.
AEA=.5%Vwater=2.1 litres.

6 DESIGN OF NORMAL AND CONGESTED COLUMN & WALL

For normal reinforced section, minimum reinforcement of column= 0.8% BD. Area of Reinforcement= 600mm^2.
Provide 6 nos. of 12mm Ø bars.
Lateral ties are 8mm Ø at 200 mm c/c.
For congested reinforced section, percentage of steel section= 1.5% BD. Bar spacing should not be less than 75mm.
Provide 12 nos. of 12mm Ø bars.
Lateral ties are 8mm Ø at 120 mm c/c.
For normal reinforced wall,

Minimum transverse reinforcement, p_t=0.2%BD.
Minimum vertical reinforcement, p_v = 0.15% BD.
Area of Reinforcement = one layer of 300mm^2/m.
Provide 8mm Ø at 160 mm c/c.
For congested reinforcement, percentage of steel= 0.40% BD.
Provide 8mm Ø at 120 mm c/c.

Fig. 6. Rebars in Formwork

7.1 Preliminary Tests

On preliminary tests of Self Compacting Concrete as in Table 2, slump flow is supervised with necessary satisfying conditions which are tabulated are as follows,

7.2 Sensor Observations

Voltage responses from the normal reinforced self compacting concrete column is recorded with one metre running length series connected sensors as V, sensors placed at 100mm, 300mm, 600mm, 850mm from bottom of formwork panel as taken as H1,H2,H3 and H4 respectively. From the Fig.7, maximum pressure on concrete can be observed at the H2 sensor pad.

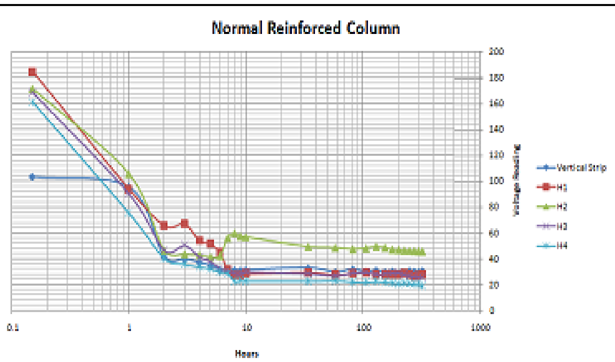

Fig.7. Normal Reinforced Concrete Column

TABLE 4
CONVERSION OF VOLTAGE TO PRESSURE

DESCRIPTION	VOLTAGE READING (mV)	MAXIMUM LATERAL PRESSURE (KN/M^2)
COLUMN-NORMAL	188	2.8
COLUMN-CONGESTED	269.1	3.6
WALL-NORMAL	342	6
WALL-CONGESTED	307	4.7

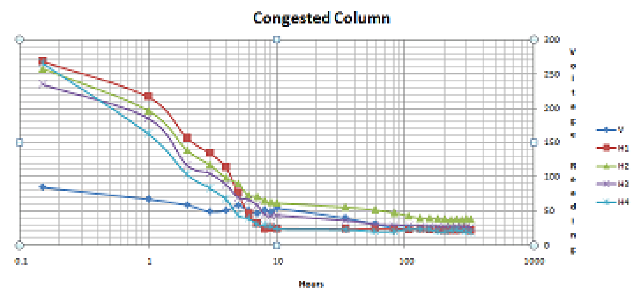

Fig.8. Congested Reinforced Concrete Column

Similarly, voltage responses for congested concrete column with similar sensor pads placed at V, H1, H2, H3 and H4 with same reference levels. From the Fig.8, maximum pressure is recorded. Pressure variation between normal reinforced concrete column against congested column is easily identified.

For wall panels of 150mm thickness and single layer of reinforcement, normal reinforced wall sections are strapped with sensors at V, H1, H2, H3 and H4 with same reference levels from the bottom. From the Fig. 9, pressure responses are recorded with maximum pressure at the H3 sensor pad.

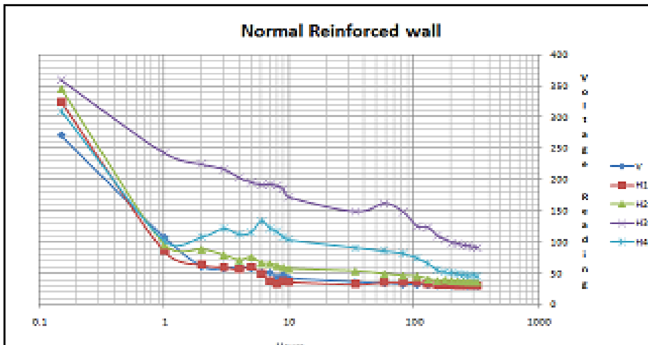

Fig.9. Normal Reinforced Concrete Wall

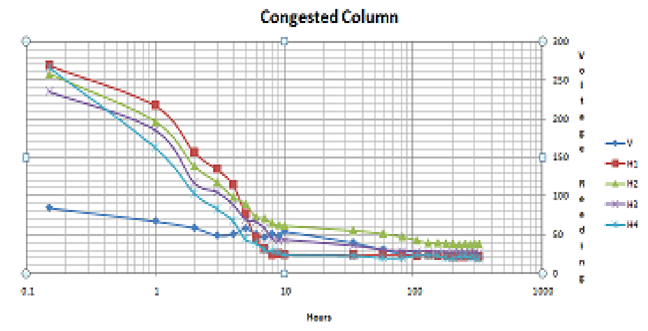

Fig.8. Congested Reinforced Concrete Wall

TABLE 3
LOAD VS PRESSURE READINGS

Compressive Load (KN)	Pressure Reading (mV)
0.05	32
0.1	66
1.5	1220
2.5	2350
5	7210

Various trials can be done by varying the aggregate proportions, superplasticiser products, sensor sensitivity and other major parameters may be introduced for exact precision for lateral pressure estimation and depending on site supervision, the expecting result shall be achieved at the best manner. By repetitive trials, the accuracy of lateral pressure shall be achieved. Proper care in handling the formwork panels and positioning the alignment props makes the concrete pouring reach great consistency irrespective of concrete volume and rate of pour. Surface finish at the completion looks more confined as self compacting concrete makes the concrete constituents fill the voids and easily flow at large heights and high level of pouring concrete.

8 RESULTS AND DISCUSSIONS

From Table 3, the voltage values shall be termed into concrete pressure in terms of Pascal. Sensor sensitivity and mode of calibration are done through UTM helps to record by applying load and removed at instants to record accurate Force values versus voltage readings.

Maximum lateral pressure is interpolated with respective voltage readings giving maximum pressure recorded as 6 KPa on 150 mm thickness wall panel. From Table 4, maximum pressure on Column with normal and congested reinforcement and wall with normal and congested reinforcement shall be observed.

With maximum pressure recorded, following studies have been understood providing safe handling of formwork components at high level of concreting which are as follows,

1. Congested reinforcement exerts more pressure at fresh stage recommends alignment prop positioning at one-third height of formwork frame.
2. Normal reinforcement column sections have constant level of pressure while hardening resulting easy deshuttering at hardened time.
3. A wall with less width exerts more concrete pressure which makes risk of formwork verticality. So proper clamping and alignment props with more attention is required for wall panel concreting.
4. With proper positioning of formwork panels, repetitive use of frame is easy for handling and transporting at different locations provided skill on work with good supervision is recommended.
5. Pressure sensors at different fluid sensitivity and long term practices can be done with proper study for further research purposes.

REFERENCES

[1] Ahmed A. Abouhussien and Assem A. A. Hassan l (2014), “Application of Statistical Analysis for Mixture Design of High-Strength Self-Consolidating Concrete containing Metakaolin”, *Journal of Materials in Civil Engineering*, 2014.26.

[2] L. Ruiz-Ripoll , S. P. Shah , B. E. Barragan and J. Turmo (2014), “Effect of Mix Design on Fresh Self-Consolidating Concrete and Inferences on Formwork Pressure”, *Journal of Materials in Civil Engineering*, 2014.26.

[3] Ahmed F. Omran and Kamal H. Khayat (2013), “Portable Pressure Device to Evaluate Lateral Formwork Pressure Exerted by Fresh Concrete”, *Journal of Materials in Civil Engineering*, Vol. 25, No.6, June 1 2013.

[4] Seung Hee Kwon , Quoc Tri Phung , Hong Yong Park, Jae Hong Kim, Surendra P. Shah (2011), “Effect of wall friction on variation of formwork pressure over time in self-consolidating concrete”, Cement and Concrete Research, 2011, pp 90–101.

[5] Mark Talesnick , Amnon Katz (2012),”Measuring lateral pressure of concrete: From casting through hardening” Construction and Building Materials, 2012, pp 211–217.

[6] A. Perrot, S. Amziane , G. Ovarlez , N. Roussell (2009), “ SCC Formwork Pressure : Influence of steel rebars”, Cement and Concrete Research,2009, pp 524-528.

[7] IS 800-2007, General Construction of Steel-code of practice, Bureau of Indian Standards, New Delhi.

[8] EN 13670 :2011- Execution of Concrete Structures.

[9] EN 12812:2008 – Falsework-Performance Requirements and General Design

[10] DIN 1045-3:2011-01- Concrete, reinforced and prestressed concrete structures-Part 3: Execution of Structures- National Annex to DIN EN 13670.

[11] DIN EN 12812:2008-12- German Vision and National Annex.

[12] DIN 18218:2010-01 – Pressure of Fresh Concrete on Vertical Formwork.

[13] De Schutter, Geert, Bartos, P.J.M., and Gibbs, John. “Self-Compacting Concrete” Dunbeath, GBR: Whittles Publishing, 2008.