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ANALYSIS AND DESIGN OF CONVENTIONAL FORMWORK SYSTEM

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Abstract: The objective of the study is to analyze the expected loads and creating a technically viable design considering the properties of the formwork components. The concepts and methods for formwork analysis and design for concrete structures are presented in this study. Since every construction is different, the formwork needs to be specifically designed and manufactured for each job. The effort needed to create a strong formwork system is just as significant as the effort needed to create the ideal steel and concrete mix for the structure's structural system. For concrete constructions, formwork has a big influence on the project's final cost, schedule, and quality. The methods of analyzing different formwork components are presented in this project to help the designer create a formwork system for the construction project. The primary focus of this study is on the design of conventional formwork, taking into account the physical characteristics of the materials and their potential for development of stresses and deflection within the component parts. Formwork is used to securely support reinforced concrete until it reaches the necessary strength. This study results into a conventional formwork that is affordable, safe, and simple to assemble on the job site. The formwork has a major impact on the final project's overall quality.

Index Terms - Analysis, Conventional, Loads, Bending, Shear, Stress, Deflection

INTRODUCTION

Design of the formwork, though important, has not received the attention that it deserves. Many formwork failures have resulted on account of either the absence of formwork design or poorly designed formwork. The design concepts specific to conventional formwork design are discussed in this study. According to the Indian standard, the formwork should be designed to meet the requirements of the permanent structure using relevant Indian standards for the materials selected for formwork. The formwork design should take into account the conditions of the materials to be actually used for the formwork, as well as environmental and site considerations. The formwork design should address Safety, Overturning, Overall stability, Prevention of collapse. Before designing the formwork, the formwork designer should get familiar with the various details such as various loads likely to be exerted on the formwork, expected loading schemes, method of concreting, sequence of concreting, and the total time of pouring the concrete.

OBJECTIVES

1. Analyse and determine different types of loads that will be carried by conventional formwork system.
2. Select the most suitable materials to be employed on the basis of loads analysed.
3. Check the adequacy of materials by determining the Bending and Shear stresses, deflection occured and its permissible limits.

RESEARCH METHODOLOGY

Concrete forms must be designed and built so that they will safely carry all live and dead loads applied to them. These loads include the weight and pressure of concrete, the weight of reinforcing, the weight of the form materials and any stored construction materials, the construction live loads imposed by workers and machinery applied to the forms, and loads from wind or other natural forces.

1.1 Dead Or Permanent Loads

The dead load consists of the self-weight of formwork, any additional temporary structures supported by formwork, and the weight of filling materials and freshly placed concrete with reinforcement steel. The code suggests determining the self-weight of formwork according to IS: 875 (Part 1)–1987, but if measurements are unavailable, it can be assumed as 500 N/m2 for initial calculations.

Table 1 Dead Loads or Permanent Loads on Formwork

Sl. No.	Load type	Suggested value of loading
1	Self-weight of formwork	Self load shall be calculated in compliance with IS: 875 (Part 1)-1987 or by actual measurement. For the sake of preliminary computations, load may be taken to be 500 N/m2 in the absence of data. The self-weight computation shall account for additional filling weights.
2	Any ancillary temporary work connected or supported by formwork	For usage in design, the actual load must be assessed. Adjusting for moisture must be considered.
3	Weight of freshly placed concrete including reinforcement	Wet concrete including reinforcement has a unit weight of 2600 kg/m3.

The weight of freshly placed concrete including reinforcement according to Indian Standards is taken to be 2600 kg/m3.

1.2 Imposed Loads

The imposed load comprises of the loads essentially from (a) lateral pressure of concrete, (b) loads from construction personnel, plant and equipment, vibration and impact of machine delivered concrete.

1.2.1 Lateral Pressure

With passage of time, concrete loses plasticity and changes into solid. Once concrete is set up there is zero concrete pressure. Internal friction is higher in dry cement than a wet one and it increases with loss of water in the concrete. The speed at which concrete changes from plasticity to solidity has considerable effect on lateral pressure.

Factors affecting lateral pressure of fresh concrete

1. Unit Weight (Density) of concrete (kg/m3)
   Pressure directly correlates with density, meaning lighter concrete exerts less pressure, while denser concrete exerts more on formwork. Higher concrete density implies higher pressure on the form face. Indian standards suggest applying a correction factor for increased density from the base considered.
2. Workability of the mix, slump (mm)
   Concrete workability denotes its ease of use for intended purposes. Pressure rises with increasing workability or slump. Low workability yields stiffer, more self-supporting concrete compared to high workability mixes. Hence, low slump concrete exerts less pressure than high slump mixes.
3. Rate of placing R (m/h) concrete in the forms
   The rate of placement is measured in meters per hour (m/h). For example, if the height of a concrete wall to be poured is 3 m and it takes two hours to pour the concrete, the rate of placing would be 1.5 m/h. Slow rates of placing enable the lower levels of concrete to start stiffening before the pour is

complete, and thus results in less pressure. On the other hand, if the rate of placing is fast, the concrete at the base of the pour will still be fluid and therefore the pressure would be more.

4. Concrete temperature (Degree Celsius)
   Elevated temperatures accelerate concrete stiffening and setting, reducing setting time, while lower temperatures prolong it. Ambient temperature influences concrete temperature, requiring slower placement in winter and faster placement in summer for optimal results.
5. Height of Concrete Pour H (m)
   The height of concrete pour means the total height of the concrete element in which concrete is being placed during one pour. This is measured in m. The relationship of concrete pressure with height and unit weight is given below:
   Concrete pressure = Unit weight X Height

1.2.2 Loads From Construction Personnel, Plant and Equipment, Vibration and Impact of Machine Delivered Concrete

Loads during construction, as per IS: 875 (Part 2)–1987, constitute imposed loads for falsework design, including those from construction personnel, equipment, concrete vibration, lateral pressure, and material storage. Code corrections are necessary if concrete is dropped from over 1.1m or accumulated excessively. Allowances are made for additional loading beyond limits, with 750 N/m2 for access. Construction loads on partially constructed structures are restricted unless specified or approved. Falsework design should accommodate force or deformation in post-tensioned members. Permanent works' load is assessed from the self-weight and plastic concrete, considering surge impact and additional loads from pumping. ACI 347 recommends formwork live loads of at least 244 kg/m2, increasing to 367 kg/m2 with motorized carts, and combined dead and live loads not less than 489 kg/m2 or 611 kg/m2 with motorized carts.

Table 2 Imposed Loads on Formwork

Sl. No.	Load type	Suggested value of loading
1	Lateral pressure of fresh concrete	Based on IS: 14687–1999
2	Loads from construction personnel, plant and machineries, vibration and impact from machine delivered concrete	Based on IS: 875 (Part 2)–1987
3	Unsymmetrical placement of concrete	Based on IS: 875 (Part 2)–1987
4	Concentrated load and storage of construction materials	Based on IS: 875 (Part 2)–1987

1.3 Environmental Loads

The environmental load on formwork consists of loads due to wind, seismic loads, earth pressure, water pressure, snow and ice load, thermal load, and miscellaneous loads.

Wind load

Formwork wind load is calculated per indian standard, akin to aci guidelines, with other horizontal loads following suit. Aci's horizontal load requirements lack documented values per chen and mosallam (1991). Bracings must withstand foreseeable horizontal loads from wind, inclined support, concrete dumping. Wall forms adhere to local wind code. Horizontal loads at floor lines should not be less than 150 kg/linear meter of slab edge or 2% of total dead load. Vertical members withstand compressive force under combined horizontal and vertical loads, per indian standards.

Table 3 Extract of Environmental Loads on Formwork

No	Load type	Suggested value of loading
1	Wind loads	Wind loads should be taken for design in accordance with IS: 875 (Part 3)–1987 subject to a minimum horizontal load equal to 3 percent of the vertical loads at critical level.
2	Earthquake load	According to relevant Indian Standards
3	Snow load	Snow loads should be assumed in accordance with IS: 875 (Part 4)–1987.
4	Ice load	Ice loads are required to be taken into account in the design of members of formwork in zones subjected to ice formation. The thickness of ice deposits may be taken to be between 3 mm and 10 mm depending upon the locations of the formwork. The maximum density of ice may be assumed to be 900 kg/m3 .
5	Earth pressure	Earth pressure can occur on falsework as in the case of retaining walls and these shall be catered for. The rise in the water table may increase pressure on the falsework.
6	Thermal load	Shrinkage and early thermal movements in the freshly placed concrete should be assessed and accommodated in the design of formwork.

1.4 Special loads

Consideration is given to the influence of all foreseeable special loads during the construction. Generally, the weight of the concrete with reinforcement can be assumed as 2500 kg/m3. Self-weight of the formwork, for ordinary structures, varies between 51 kg/m2 and 76.5 kg/m2.

1.5 Materials specific to study

1. Plywood: Types, materials, manufacturing process, thickness, dimensions, tolerances, values of Modulus of elasticity and Modulus of rupture shall be in accordance with IS: 4990–2011. Plywood specifically chosen for this study is 2440m x 1220m 12 mm thick plywood board.
2. Tubular Section: Permissible stresses for axial bending for tension and compression, bending, shear, bending and axial combined and weld stresses pertains to IS: 806–1968. Primary members (square tube 50x50x2.6) 210 MPA and secondary members (ISMC 100 250 MPA span 1.24 m) specified according to IS code 806-1968 and IS 4923-1997
3. Timber: Basic permissible stresses of different species of timber selected out of the timbers listed in IS: 399–1963 shall be taken in accordance with the stresses given in IS: 883–1994. Wooden battens 2”x3” are used specifically.
4. Steel: The permissible stresses shall be assumed as given in IS: 800–2007 and IS: 2750–1964, as applicable.

1.6 Permissible Stresses

Permissible stresses should not exceed the values specified in the relevant Indian Standards for permanent structures.

Table 4 Permissible bending and shear stresses

Component	Member	Permissible bending stress	Permissible shear stress
Slab	Ply 12 mm thick	Modulus of rupture/factor of safety OR as per IS 4990 2011 page 3	10 kg/cm^2 value as per commercial ply.
	Square tube 50x50x2.6mm	0.66 x fy (yield strength)	0.4 x fy (yield strength)
	ISMC 100 1.54 m	0.66 x fy (yield strength)	0.4 x fy (yield strength)
Beam	Ply 12 mm thick	Modulus of rupture/factor of safety OR as per IS 4990 2011 page 3	10 kg/cm^2 value as per commercial ply.
	Wooden batten 2”x3”	Allowable bending stress 95 kg/cm^2 as per NBC part 6 page 15	Max shear stress 12 kg/cm^2 as per NBC part 6 page 15
	Square tube 50x50x2.6mm	0.66 x fy (yield strength)	0.4 x fy (yield strength)
	ISMC 100 1.24 m	0.66 x fy (yield strength)	0.4 x fy (yield strength)
Vertical including footing and columns	Ply 12 mm thick	Modulus of rupture/factor of safety OR as per IS 4990 2011 page 3	10 kg/cm^2 value as per commercial ply.
	Wooden battens 2”x3”	Allowable bending stress 95 kg/cm^2 as per NBC part 6 page 15	Max shear stress 12 kg/cm^2 as per NBC part 6 page 15
	Walers-2MC75	0.66 x fy (yield strength)	0.4 x fy (yield strength)

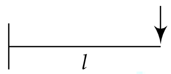
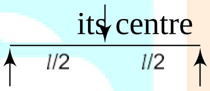
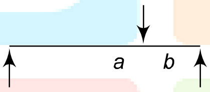
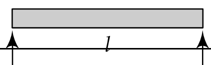
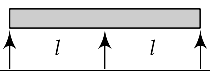
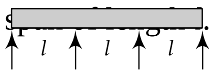
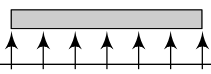
In the absence of detailed specification, acceptable and frequently used values of permissible deflections can be taken as given in Table 5

Table 5 Permissible Deflection for Guidance

Sr no	Type of member	Permissible deflection
1	For members up to 1.5 m	3.0 mm
2	For members spanning more than 1.5m	6.0 mm or span/360, or span/270

1.7 Maximum Bending Moment, Shear Force, and Deflection Formulae

Table 6 Maximum Bending Moment, Shear Force, and Deflection for Varying Loading and Support Conditions

Sr no	Loading condition	Bending moment (M)	Shearing force (V)	Deflection
1		Pl	P	$Pl^3/3EI$
2	For simply supported beam with concentrated load *P* at its centre 	Pl/4	P/2	$Pl^3/48EI$
3	Span = $l = a + b$ 	Pab/l	Pa/l	Pb/EI x $(l^2/16)-(b^2/12)$
4	Two point loads of magnitude *P* each. Span = *l* 	Pa	P	(Pa/6EI) x $(3l^2/4)-(a^2)$
5	For simply supported beam with U.D.L. Span of length *l* 	$wl^2/8$	Wl/2	$5wl^4/384$ EI
6	Two span uniformly supported beam with U.D.L. Equal span of length *l* 	$wl^2/ 8$	5wl/8	$wl^4/ 514$ EI
7	For continuous beam with U.D.L. over its full length. Equal span of length *l*. 	$Wl^2/10$	5WL/8	$Wl^4/185EI$
8	Continuous beam more than 3 spans with U.D.L. over its full length. Span of length *l*. 	$Wl^2/10$	5WL/8	$Wl^4/185EI$

1.8 Assumptions made in Formwork Design

1. All loads are assumed as uniformly distributed.
2. Beams supported over three or more spans are regarded as continuous and approximate formulas given elsewhere are used.
3. The stresses induced in every member of formwork, in bending, in shear and in bearing, should be within the permissible working stress for that material.
4. Forms must be so designed that the various parts will not deflect beyond the prescribed limits. The permissible deflection depends on the desired finish as well as the location.

RESULTS AND INFERENCES

From the studies of different types of loads, materials specifically selected, permissible stresses and bending, shear stresses and deflection equations, design calculations are conducted to check the adequacy of the selected formwork system for loadings which are likely to occur during the casting of concrete members.

Table 7 Bending stress, Shear stress and Deflection values after load analysis*

Component	MEMBERS USED	Bending stress (kg/cm^2)		Shear stress (kg/cm^2)		Deflection (mm)		Remark
		Actual	Permissible	Actual	Permissible	Actual	Permissible	
Slab	Plywood 12 mm thick	57.83	150.00	2.49	10.00	0.95	3.00	Safe in bending, shear and deflection
	Square tube 50x50x2.6 mm , span 1.24m	1105.00	1386.00	143.73	840.00	0.07	3.00	Safe in bending, shear and deflection
	ISMC 100, span 1.54 m	734.58	1650.00	150.00	1000.00	0.01	6.00	Safe in bending, shear and deflection
Beam	Plywood 12 mm thick	65.00	90.00	2.85	10.00	1.48	3.00	Safe in bending, shear and deflection
	Wooden battens 2”x3”	34.23	95.00	5.33	12.00	0.11	3.00	Safe in bending, shear and deflection

	Cross members Square tube 50x50x2.6 mm , span 1.24m	1100.00	1386.00	555.00	840.00	1.29	3.00	Safe in bending, shear and deflection
	Supports of cross members ISMC 100, span 1.24 m	1100.00	1650.00	425.00	1000.00	1.00	3.00	Safe in bending, shear and deflection
Vertical formwork incl. column and footings	Plywood of size 2.44m x 1.22m 12 mm thick	82.84	150.00	5.29	10.00	1.65	3.00	Safe in bending, shear and deflection
	Wooden battens 2"x3"	85.66	95.00	10.21	12.00	0.61	3.00	Safe in bending, shear and deflection
	Walers – 2MC75	380.00	1650.00	188.00	1000.00	0.28	3.00	Safe in bending, shear and deflection

*Values are rounded up to 2 decimal places

From the derived values of actual stresses and permissible stresses, it can be concluded that the designed conventional formwork system is adequate for the job. Values of actual stresses are lesser than the permissible values which indicates towards a safe and resilient formwork system; which is capable of carrying all sorts of loads and stresses it is designed for. The intricate dynamics of load transmission within structural elements such as slabs, beams, columns and footings have been dealt during the design phase of system.By employing rigorous analysis techniques, inclusion of the critical factors influencing the distribution and magnitude of these loads has been made.

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List of referred Indian standards codes

1. IS CODE 875-1987 - Code Of Practice For Design Loads (Other Than Earthquake) For Buildings And Structures
2. IS CODE 14687-1999 - Guidelines For Falsework For Concrete Structures
3. IS CODE 4990-2011 - Plywood For Concrete Shuttering Works — Specification
4. IS CODE 806-1968 - Code Of Practice For Use Of Steel Tubes In General Building Construction
5. IS CODE 4923-1997 - Hollow Steel Sections For Structural Use - Specification
6. IS CODE 883-1994 - Design Of Structural Timber In Building -Code Of Practice
7. IS CODE 800-2007 - General Construction In Steel — Code Of Practice
8. IS CODE 2750-1964 - Specification For Steel Scaffoldings