MULTI FUNCTIONAL PERFORMANCE OF PRECAST PLANER ELEMENTS AND SUSTAINABILITY

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ABSTRACT. General types of planner system used in precast concrete construction is discussed in the beginning in this paper. The utility of planner system as wall or roof elements in construction of building envelope is highlighted. The performance requirements of such elements of envelope include thermal, acoustic and visual (day light inclusion) efficacy, resistance against fire hazard, resistance against moisture ingress besides, structural safety against both gravity and horizontal loads including safety of joints. In addition one may also look for performance against serviceability limits including durability during intended design life. Various performance requirement in terms of properties of concrete and construction elements are elaborated, e.g. thermal conductivity and diffusivity for energy efficiency etc. It is highlighted in this paper that precast concrete wall or roof elements in the envelope can exhibit multi-functional performance capability with appropriate design, thus may boost economy in construction and also may enhance sustainability, especially in tropical conditions. Main tropical climatic zones, precipitation zones and seismic hazard zones are considered and super imposed over one another to identify new zone classifications for building elements and performance requirements are highlighted considering both safety and sustainability. The relevant properties of concrete determined experimentally earlier or through models proposed in past works at IIT Delhi are presented. These research outcomes are considered together with information available in literature to demonstrate the sustainable performance efficiency of precast wall and roof system in tropical conditions.

Keywords: Sustainability, Precast concrete, Tropical condition, Multi-functional performance, Planer elements.

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INTRODUCTION

Shortage of housing is recognized by Govt. of India and thus GOI launched the "Pradhan Mantri Awas Yojana-2015" (PMAY) that envisages for providing housing to all by 2022 with an emphasize on affordable housing [1,2]. Out of the total 330.84 million houses in the country, 24.67 million houses are lying vacant generally at higher affordability level. The housing shortage currently being faced is mostly by the (economically weaker section) EWS and (lower income group) LIG category of the population, with EWS group facing accounting for 56% of the shortage [3]. These numbers indicate that merely constructing houses is not enough, but the constructed houses shall be "affordable" to the intended target population, otherwise would remain "vacant" without reducing the "housing shortage".

Solving of the above problem of shortage of housing, over a short period of time, is only possible through pre-cast industrialized building construction. Reduced cost of production of houses can be realized by reducing the material consumption, in addition to reduction of labour cost. However, initial cost of setting up of the plant breaks even only when volume of construction is large. This is possible in case of large scale mass production of affordable houses. Reduced material consumption leads to environmental and economic sustainability and affordability leads to social sustainability.

The affordable houses must satisfy the minimum functional requirements. These functional requirements are: thermal comfort, adequate daylight levels, acoustic comfort, fire resistance etc., besides being structurally safe. To minimize the material requirement the elements in the building envelope shall be multifunctional. Linear precast elements such a columns and beams generally require, in-fill walls to take care of most of the functional requirements. Planner elements such as load bearing Reinforced Concrete (RC) wall on the other hand can fulfil both functional as well as structural requirements. Hence in this paper multi-functional utility of precast planner element is focused.

PRECAST RC PLANNER SYSTEMS

Precast RC system can be classified according to their geometrical configuration as linear system mentioned earlier, planner or panel system and three dimensional and box section. Among these planner system is most widely used for floor slab, vertical supports, partitions, and exterior walls. They form the skin of the enclosures [4,5]. The examples are room sized slab supported on wall panels, i.e., cross walls or exterior walls. Non-pre-stressed flat slabs, hollow core un-pre-stressed and pre-stressed slabs, double Tee or single Tee pre-stressed and ribbed slab etc. are examples of planner floor slabs. Exterior load bearing walls, light weight partition walls and sandwich wall etc. are examples of planner wall systems. Joints at junctions play major role in their performance.

By combining the structural performance with functional performance these systems enable economy. The functional aspects those needs considerations are a) thermal, b) acoustic, c) provisions of appropriate fenestration for ventilation and daylighting, d) fire resistance and other fire protection related performances etc. These performance requirement for panels used enclosure and partitions are discussed in the subsequent sections. Box or three dimensional systems can also perform some of the functions performed by planner elements, however, advantages of productions and simplicity makes planner system more popular.

THERMAL AND ACOUSTIC PERFORMANCE

Thermal Performance

Thermal performance of wall, ceiling and roof elements in a conditioned building are evaluated in terms of their U-values, i.e., thermal transmittance. U-value is a function of thickness of concrete element and thermal conductivity of concrete. Lesser thickness of load bearing wall element would increase the U-value hence lower the insulation quality. In such case one may use sandwich construction with insulating core and concrete leaves or increase thickness of RC element to minimize the life cycle cost that involves energy cost during operation of the building. The other factor in U-value is the thermal conductivity of concrete, which depends upon aggregate type, porosity moisture content etc., (6,7). For hollow core slab the U-value would depend upon volume fraction of voids and thermal resistance of voids.

For naturally conditioned building in tropical climate the thermal performance is governed not only by U-value but by volumetric heat capacity and thermal storage also. The thermal storage manifests itself in the form of an amplitude decrement in diurnal periodic temperature wave with a phase lag expressed in time unit. The heat capacity is governed by density, specific heat and thickness of the element. Such performance can be estimated through heat transfer modelling using transmission matrix concepts (8). Volumetric heat capacity of concrete does not vary significantly from aggregate to aggregate, but depends strongly on moisture content. For hollow core slabs, voids do not contribute to volumetric heat capacity.

Acoustic performance

The noise insulation characteristics is important functional requirement for planner building elements such as floors, partition walls, external walls etc. The noise insulation is characterized by Transmission Loss values in dB. For homogeneous mass, such as RC elements the TL value is governed by mass law in the frequency domain of interest in buildings and is given below in equation 1(9).

$$TL = 18 \log M + 12 log f - 25 \ldots\ldots \quad (1)$$

Where M is area density of wall in kg/m^2; f is the frequency. Thus noise insulation quality is governed by thickness and density of material. However, for a double leaf wall with cavity inside or a sandwich construction with soft insulating core can provide much higher noise insulation in terms of TL values. Hollow core slabs exhibit high noise insulation quality due to presence of voids.

DAYLIGHT, VENTILATION AND FIRE RESISTANCE

Daylight, ventilation and fenestration insertion

Daylight penetration, natural ventilation depends on fenestration size, location of the openings on the wall, orientation of the wall with respect wind direction etc. The openings can be incorporated easily in the planner system; thereby, daylighting and natural ventilation performance can be appropriately imbibed in these precast wall elements.

Fire resistance

Fire resistance of concrete elements is function of cover depth and for RC elements, one conservative limit state criteria for fire resistance is the time of rebar attaining a temperature of 550°C. Simple empirical formula given below can be used for approximate estimation of fire resistance, without going through rigorous numerical analysis (10).

$$\Delta \boldsymbol{T} = \boldsymbol{n_w n_x \Delta T_g} \ldots \qquad (2)$$

Where;

$$n_w = 1 - 0.061t^{-0.88}$$

$$n_x = 0.18 ln u_x - 0.81$$

$$\boldsymbol{u_x = \frac{a}{a_c} \times \frac{t}{x^2}}$$

t is time, x is the distance from fire exposed face for a planner element with one dimensional heat transfer where one surface of the element is exposed fire. a is thermal diffusivity of concrete and a_c is the thermal diffusivity of reference concrete, equals to 0.417×10^{-7} m^2/s. ΔT is the temperature rise at the rebar level and $\Delta T_g = 345 \log(8t+1)$, represents the rise in gas temperature according to standard time temperature curve used for fire resistance determination as par definition of fire resistance.

As apparent from above equation the fire resistance is governed by thermal diffusivity of concrete and cover thickness. Higher the insulation quality, lesser is the cover requirement of panel.

MULTI FUNCTIONALITY OF PLANNER SYSTEM

Through discussions presented in preceding sections it is evident that precast planner element can perform multifunctional task, thus eliminating the need for separate components for each different functional requirement. Thus their adoption in building construction can reduce the material consumption enhancing sustainability and cost reduction. Cost reduction however, would depend upon volume of construction as initial cost of setting up of plant may be high, and; only after achieving a break-even construction volume cost of production would be economic. Considering life cycle cost can demonstrate the economic advantage of such a system over other systems. The issue of affordability can then be resolved in a simple manner. Thus economic, social and environmental sustainability can be achieved in one go. The design process for system may need adoption of multi objective optimization techniques, to satisfy all the requirements simultaneously.

CONCLUDING REMARKS

The paper presents some of the functional requirements related to building enclosure elements and partition walls, floors and roof etc. Further it is established that precast planner system can perform multi-functional task in one go to achieve sustainability.

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