IJEASM
International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 2 Issue 2, February 2021

A Review Paper on Progressive Analysis of RC Building Framed Structures Subjected To Work Progress Load

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Abstract: *The design of RC building framed structures is based on current codes of practice. The sophisticated tools and techniques are being used for the analysis and design of RC framed structures. Despite of utmost care in design and construction work and even after more than a century of its use, many a times the RC buildings suffer from damage while the construction work is in progress. The damage in such a case ranges from minor to major serviceability failure or distressed structural elements to collapse of an element or few elements or the entire partly built building frame. Such failures are evidenced in Gujarat state, Nationwide and also reported in literature to take place Worldwide. The partly built building frame subjected to loads incidental to construction work (the Work Progress Load; WPL) require consideration in the design. In absence of the code specifications for WPL, the designers ignore the assessment of its effect during construction, routinely. As none of the National codes have provided probabilistic value of partial safety factor for loads, as a result, the study has been carried out to find out the partial safety factors of DL and components of WPL in agreement with various National codes such as IS 456:2000, ACI 318 -14, BS8110 -1: 1997, AS 3600-2009, CSA23.3 – 2014, JSCE No 15, NZS 3101: Part 1:2006. Additionally, the WPL due to weight of green concrete which is based on density of green concrete is validated with the unit weight given in IS 14687:1999*

Keywords: *RC building frame, Work Progress Load, green concrete, formwork, stockpiled material, load combination, partial safety factor, shores, re-shores, partly built building frame, construction stage, sequential analysis.*

1. Introduction

In recent time, the RC buildings are very well designed and detailing of steel reinforcement is provided as per specification in the code of practice after gaining the knowledge over a period of more than a century. The sophisticated tools and techniques are being used for the analysis and design of RC framed structures. The buildings are constructed with utmost care using the best materials and techniques at the site. However, many buildings fail in providing efficient services. Many times, it requires to attend the maintenance work after the small duration of time after the building is put into service. Despite of utmost care in design and construction work and even after more than a century of its use, many a times the RC buildings suffer from damage while the construction work is in progress. The damage in such a case ranges from minor to major serviceability failure or distressed structural elements to collapse of an element or few elements or the entire partly built building frame. Such failures are evidenced in Gujarat state, Nationwide and also reported in literature to take place Worldwide.

Research Motivation

During the forensic investigation of a failure in a building, it was revealed that the stresses exceeded the design strength of structural elements during the construction in a partly built building frame. Further, it was revealed that limit state of serviceability, or limit state of collapse could be reached during the construction; prior to the building is put into service. The impaired serviceability condition reduces the efficiency of the building and reduces the durability of the RC structures.

The partly built building frame receives the load due to construction (Work Progress Load, WPL) for the short duration and is distributed through the existing structural elements. There is no specification available regarding the estimation of WPL, incorporating it in structural analysis during different stages of construction. Hence, even though a sophisticated structural analysis is being performed, the building does not perform satisfactorily

2. Objectives

a) To identify and quantify the WPL components as follows:

(i) WPL due to weight of green concrete,
(ii) WPL due to LL (Live Load) during pouring of concrete,
(iii) WPL due to weight of formwork,
(iv) WPL due to stockpiling of materials.

b) To identify the load combination and to propose corresponding partial safety factors to be used in limit state method of design.

c) To assess through sequential analysis the effect of construction sequence of RC building frame structures on stress resultants.

d) To incorporate the strength parameters of premature concrete while evaluation of design strength of elements.

Scope

The present work includes following design aspects of RC building framed structures applicable to partly built building frame while in construction.

(i) Work Progress Load (WPL) and their distribution,
(ii) Linear structural analysis of floor slabs and partly built building frame.
(iii) Other Design Attributes: Load combination, partial safety factors and strength of premature concrete.

3. Literature Review

Manuel B.et al have presented compilation of recent collapses during construction including an analysis of their causes and with remedial measures. Authors intended to develop an understanding about why building structures can collapse during the construction phase. The motive for the publishing the research paper was to publicize the causes and hence to avoid the similar mistakes being committed in future (18). Amongst the pioneering work Nielsen, through his analytical studies evaluated the sharing of WPL on shores and re–shores(19).
Grundy & Kabaila used the simplified method for evaluation of WPL distribution on supporting floors through simplified assumptions(20). They assumed the shores were infinitely rigid compared to the slabs displacing in the vertical direction. It was concluded that the WPL may exceed the design load of floor slab and therefore it cannot be neglected in design. Numerous studies have been conducted in the past to estimate the WPLs and their distribution (15), (16), (21). The different components contribute to the WPL. The researchers (22),(23),(24),(25) have estimated values of different components which contribute to the WPLs. The purpose of estimating the load components and the evaluation of their effect were varied in those cases.
Saeed Karshenas et al., estimated the live loads on the formworks due to materials and equipment stored and the worker's load on the slab formwork (22). ASCE publication (25) recommends to include the contribution of materials, personal and equipment loads to the WPL. The code specifies horizontal WPL to be considered while in constriction. Many researchers (15),(16),(26),(27) from different countries made efforts to evaluate the shores and re–shores load at different floor levels through analytical or experimental approaches. Vollum et al. assessed the influence of work progress loading on deflection in RCC slab(28). It was suggested that long term deflection in slabs could be governed by short term construction and peak WPLs. Through the experiments on one-way slab in the structural laboratory it was concluded that the final deflections were greater than the permissible one based on the code of practice. Earlier studies (29) regarding WPL analysis were based on analytical models. Simplifying assumptions were taken there to evaluate the effect of WPL. Liu, Chen W.F., developed a refined computer program to incorporate the effect of shore slab interaction realistically compared to the earlier simplified method adopted by the researchers. The limitation of the model were identified by the authors (16) as (i) shore-slab interaction was 2D

problem, (ii) The slabs behaved elastically (iii) The shores and re-shores were assumed continuous, uniform elastic supports having finite axial stiffness and (iv) The foundation was assumed rigid. It was realised that simplified methods could predict the location and construction step to evaluate the internal forces in slabs but that underestimated slightly the amount of load.

Liu X. et al. (16) proposed a 3D computer model to incorporate the effect of foundation rigidity, column axial stiffness, slab aspect ratio and shore stiffness distribution for evaluation of WPL distribution and the stress resultants in supporting slabs. The probability distribution of maximum shore loads in multi-storey RC building were evaluated by Xi-
La Liu et al. (26) and El-Sheikh Magdy et al.(15) It was concluded that amongst all the variables the variation in live load affects the maximum shore load significantly. The time dependent analysis, based on numerical approach was performed by Hyo-Gyoung et al. (30). The time dependent analysis was performed considering types of shoring system, the shore stiffness, shore spacing, creep and shrinkage of concrete and construction sequences of frame structures. Based on the study, the efficient shoring and re-shoring system were recommended. The loads during construction transmitted through shores and re-shores were experimentally evaluated (31) for multi-storey RC building with flat plates; provided at floors. The loads due to dead load and live load during construction on shores and re-shores were evaluated. It was recommended to develop a good data base for assessing the loads in shoring systems through the field survey by using improved instrumentation. The information on the magnitude and variations in load effect on structure during construction was highlighted in the qualitative analysis described in (21). It was concluded that a magnification factor of 2.0 may be appropriate to account for variability among a group of shores in common pour area, which may be attributed to pre-compression exist in shores. Significant load variation in steel shores were observed due to large daily temperature variations. Small decrease in shore load was attributed to gaining of strength and stiffness of supported slab with age. The effect of shore removal varies the amount of load transferred to shores and supporting floor slab.
Fang Doping et al. defined the structural characteristic parameter which depends on ratio of slab flexural stiffness after 28 days curing and shore-stiffness per unit slab area(24). It was concluded that the load distribution and the maximum slab loads depend on shoring/re-shoring schemes adopted and the structural characteristic parameter.
The loads of green concrete and other loads are primarily carried by the supporting formworks and gets transferred to the supporting floor. The specifications for load evaluation on formwork and the self-weight of formworks are included in design specifications (10), (32), and assessed for the purpose of design of formwork. However, the loads to which the partly built building frame is subjected would be the fraction of WPL acting on the building frame. The researchers have proposed the transfer of loads through shores and re-shores to the supporting floor slabs through analytical (20), (19) and the experimental works (31).
The floor slabs are supported on shores in RC building. Manuel et al. proposed the process for estimating loads on the shores during construction of RC buildings. They proposed the method to estimate the maximum load on floor in a simple way without the need for specialised software(33). Manuel Buitrago et al proposed a method to find the load on individual shore for each construction face and that to without use of advanced software. (34).
The probabilistic model for construction load for RC building was proposed by David V. Rosowsky et al. The model considered the loads causing peak structural action and it described probabilistic model for slab self-weight, construction live load, stocked piled material load and moving loads. The construction load was derived from Monte-Carlo simulation and it was compared with service load. It was concluded that mean construction load exceeds mean maximum service load whenever the nominal live to dead load ratio is less than about 1.0 (35). The state of the art knowledge on the transmission of loads between slabs and shores during the construction of RC building structures is presented in (36). It is suggested to develop new elements to increase the safety and robustness of temporary shoring structures.

4. Methodology

The work progress load (WPL) is because of furtherance of RC building frame. The partly built building frame carries this load over and above its own weight. The WPL is not accounted for in routine design because it does not exist in completed structure. The importance of WPL is not realized because the ill effects produced are hardly noted, reported or communicated to the society.

Identification of WPL

A broad definition of WPL can be given as loads and effects to be considered, likely to act or affect the building structures while under construction. The nature and types of WPL are similar to those considered routinely to evaluate the design load. However, the WPL or effects differ due to they act (i) on partly built frames, (ii) for short duration, (iii) because of execution of work and (iv) while building passes through different stages of construction. The primary load that can damage to building structures is gravity load component of the WPL.

The gravity loads which are not accounted for in the design because they are not identified by national codes for consideration in design. Only a “caution” remark is found in Indian codes (2), (4) (3) and in many other country codes (43), (47), (50) with respect to consideration of WPL in the analysis and the design.

The primary gravity load that requires to be carried by the partly build building frame and to be safely transmitted to the foundation are as depicted in Figure 4.1 and Figure 4.2. The part of WPL as depicted either vanish or become the part of the complete structure on progress of construction work.

The WPL is formed of four different components:

1) The weight of green concrete:

This weight is because of weight of fresh concrete poured in the formwork after placement of reinforcement cage. It is the weight considered of the structural element having finished concrete surface prepared to match the designed dimension of structural element.

2) The weight of formwork:

The weight of formwork includes the weight of falsework and the formwork after the assembly. The falsework and the formwork, which is ready to receive the reinforcement cage and fresh concrete, is identified to generate the weight of formwork.

3) The live load:

The live load is the weight of and impact effect if any of the assembly of person, weight of equipment, weight of stored material etc. which facilitates the pouring of concrete.

4) The weight of stock piled construction materials:

The weight of stocked pile material is identified as a component of WPL because of a common tendency of stockpiling construction related materials on newly created floor surface to facilitate the further construction work.

All these loads are acting during the construction of building frame and during the process of gaining the strength of supporting RC floor. Some of these loads act together or some of them are mutually exclusive.

5. Conclusion

1. The building structures pass through different construction stages and the incomplete structures are liable for safe transmission of the work progress load over and above the dead load of partly built building structures. The work progress load consists of (i) Weight of green concrete, (ii) Weight of formwork, (iii) Live load during construction and (iv) Weight of stockpiled material. Some of these loads act simultaneously while some of them are mutually exclusive.

2. The unit weight of concrete is different in different state of consistency. The unit weight of reinforced concrete also varies significantly for commonly adopted percentage reinforcement in RC structural elements. The unit weight of green reinforced concrete is proposed 26kN/m3 for the purpose of evaluation of WPL due to weight of green concrete.

3. The characteristic weight of green concrete per unit floor area is 6.32kN/m2 for ‘all categories of buildings’ are considered. This load intensity is higher for Government buildings while lower for private buildings.

4. The WPL due to weight of formwork is 60% higher than the weight as proposed in Indian Code of practice (11).

5. The WPL due to live load is significant when the concrete is placed through trolley or pumped on to the floor slab. The minimum intensity of live load is 1.5 kN/m^2 when concrete is poured manually.

6. The WPL due weight of stock piled material and the WPL due to live load are mutually exclusive. The WPL due to stockpiled material require attention of the designer when placing of material is not prescribed.

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