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Investigation of service stress in medium rise building design in Sri Lanka according to selected design codes

Eng. K. Kajeenthan
Faculty of Engineering,
University of Jaffna.
Sri Lanka.

Eng. M. Vignarajah
Faculty of Engineering,
University of Jaffna.
Sri Lanka.

Abstract— This paper presents the study of service stress appear in various structural elements in the design of medium rise reinforced concrete building in Sri Lanka using selected codes. Five structural design codes have been considered for the study. Namely EN1992:2004, BS8110:1985, IS456:2000, AS3600-2009 and ACI318-2014. Comparisons of the provisions for actions, and for the resistance of sections in flexural and axial loading are carried out. The differences in the service stress in respective designs have been estimated and reported.

Keywords— **service stress, reinforced concrete, medium rise building.**

I. Introduction

The modern construction industry is facing a new problem that heavy material usage in the medium and tall building designs. Material usage is governed by the design code based on the structural framing. Even though the design philosophy is same (ultimate limit state), it is crucial to find a design code that minimize cost while satisfying design. This paper presents a quantitative study of service stress appear in an apartment type building which is designed according to the selected codes mentioned above. In this case study, material optimization is considered. It is too complicated to include labour and other cost involved, therefore the material optimization of individual structural components such as beams, columns, slabs, walls and staircase are commonly adopted. The material optimization is based on minimum weight to maximum load carrying capacity. The main factors to be considered are the costs of steel reinforcement and concrete. The service stresses arising from load combination and structural framing will directly govern the section sizes. In this study, the sections were sized based on ultimate limit state design and then the service stresses were estimated.

There are many comparative studies for the design of service stress included in different design codes. The study by [Leopold MBEREYAHO 2018] established that the economic advantage expressed through saving in materials cost when considering service stress, and this consolidated the fact that the most of the designers considering this service stress currently in use for design of all important structures all around the world. Focus is usually given to evaluate the differences in load intensities, load factors, nominal resistance values stipulated in design codes from United States, Europe, and Japan [Nandi and Guha]

compared the Indian and European design codes considering the material properties, limiting percentage reinforcement area for different elements, and design formulas used for calculating ultimate capacity for such elements [ElShennawy et al] .[Hawileh et al.] performed a full comparison of the ACI-318 and EC2 design codes considering flexural calculations only. The authors concluded that the EC2 provisions provide a larger safety factor than those for ACI-318. However, the difference is negligible for live/dead load ratios larger than 4.0. [Tabsh] focused on comparing the ACI 318 code against British BS 8110 code regarding the flexural, shear, and axial compressive capacity of members. The study included examining different cross sections while considering different values of live/dead load ratios. The author concluded that the ACI 318 code results in larger cross sections and higher reinforcement percentages than BS 8110.

Due to the ever increasing cost of the reinforcement, the optimal sections tended to provide low reinforcement; in most sections [Bordignon and Kripka 2012]. In the design of building skeleton the axial elements are more economy than flexural elements. Therefore careful arrangement of grid also plays an important role in this design [Ceranic and Fryer 2000]. The material costs of RC elements depend on their dimensions, reinforcement ratios and the unit costs of concrete and steel reinforcement [Saini et al. 2006]. As pointed out by [Karihaloo and Kanagasundaram 1993] labor cost may be included in each ingredient. The objective of optimization (e.g. minimum cost or weight), the design variables and the constraints considered by different studies vary widely and therefore, different optimization methods have been employed to provide the optimal design of RC Concrete Building [Rahmanian et al. 2014].

This paper focuses on the considered actions (loads) and used design procedures for different structural elements such as, beam, column, wall, slab, and staircase while considering element service stress and then estimating concrete volume. Similarities and differences between the considered design codes are evaluated. The study is meant to provide insight into the applicability of different design codes and comparing the service stresses in long run. The study also shows that design of building using limit state theory and the variation of service

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stress across the spectrum of elements. Estimation of service stresses in various structural elements are very important to understand the long term relaxation behavior in steel and how the stresses are transferred to concrete. In practice, each one of those design codes will result in service stresses that may significantly vary among beams, columns, slabs, walls and staircase.

II. Methodology

The medium rise commercial building was selected for this study. With the help of chief engineer, all the details about the selected building have been obtained and then modeled by using SAP 2000 software package. Loadings were assumed and compared for the type of commercial building. First, the actions and load factors stipulated in different design codes are estimated. The model is prepared by considering actions:

1. Permanent actions (DEAD,SDEAD) and variable actions (LIVE)
2. Types of building occupancy for variable actions (rooms, corridor, lobbies, staircase)

The corresponding load intensities were estimated with different design codes. Afterward, the resistances of several structural elements were evaluated for different structural members by using general purpose finite element software package SAP2000. All the members were designed by using different codes. The material properties were fixed throughout the study as follows: Material used as high strength steel with 500 MPa, and concrete compressive strength of 30 MPa.

A. *Numerical model*

In the numerical study, a finite element model was prepared by using SAP2000. The structure has several spans with maximum span length of 7.2m. The adjucent panals were checked to makesure that the ratio os span lengths are less than 15%. Standard section sizes are considered for beams, columns and shear walls for every floor.

The figures (1) and (2) show floor plan and proposed layout of the selected building respectively.

Figure 1. Floor plan of Selected Building

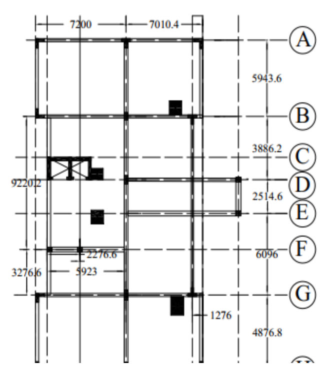


Figure 2. Proposed Layout of Typical Building

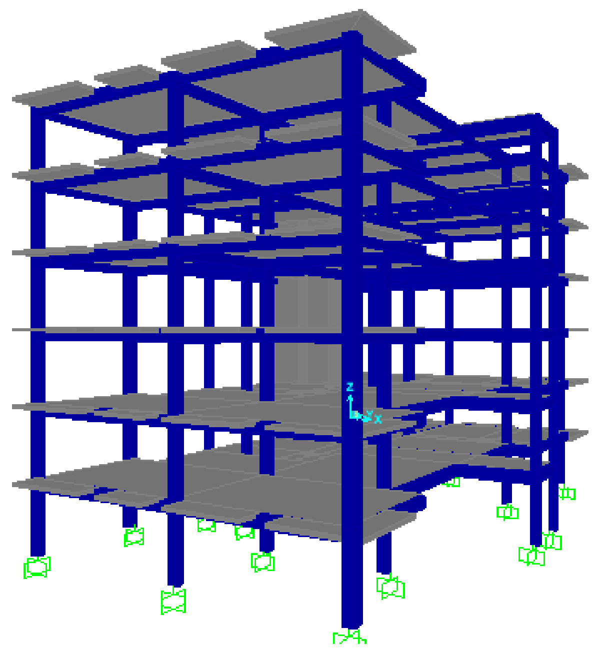
The Table (1) illustrate the initial sizes of the elements. Initially each and every member from different design codes have been assumed as same sizes.

TABLE 1.INITIAL SIZES OF MEMBERS

Members	Beam	Column			Slab	Lift core	Staircase	
		Rectangular	T-Type	L-Type			Rise	Going
Dimensions (mm)	300x400 300x500	300x300 400x400	400x400	400x400	125	200	175	250

In this finite element model, frames were used for columns and beams ; thin shell elements were used for slabs, staircases and walls of the structure. The finite elements were discretized as follows;

beams and columns were assumed as rigid and subdivided by common nodes. Slabs and walls were divided considering aspect ratio. The minimum and maximum values of aspect ratios were 1.0 and 1.5 respectively.3D view of the finite element SAP2000 model is shown below.



B. *Load combos*

Figure 3 .SAP 3D Model of Six Story Building

In this paper wind and earthquake loads are not included. The following table gives load combination factors.

TABLE 2.TYPICAL LOAD COMBINATION FACTORS FROM DIFFERENT CODES

DESIGN CODES	*LOAD FACTORS*	
	DEAD	*IMPOSED*
BS8110	1.40	1.60
EN1992	1.35	1.50
IS456	1.20	1.20
AS3600	1.20	1.50
ACI318	1.40	1.70

C. *Load intensity*

The Table(3) presents some values of variable actions (LIVE) specified for different types of building occupancy. Large differences in live load intensities are noticed for balconies and corridors in residential buildings. Values of variable actions (LIVE.) are combined with permanent actions (DEAD), and then each is multiplied by relevant load factor for ultimate limit state .Considering Dead Load (D.L) self-weight of each members were added together with corresponding values.

TABLE 3: LIST OF DEAD & LIVE LOADS

***LOAD INTENSITIES* (kN/m²)**

	BS8110	*EN1993*	*IS456*	*AS3600*	*ACI318*
D.L					
Services	1.00	1.00	0.49	1.00	0.50
Finishes	1.00	1.00	1.91	0.50	3.83
Partitions	1.00	1.00	1.98	0.50	0.50
L.L					
Floor	1.50	2.00	2.0	1.50	2.40
Staircase	3.00	3.00	3.0	2.00	1.92
Balcony	4.00	4.00	3.0	2.00	2.87

III. ANALYSIS

The linear static analysis was performed in order to get the final results. Figure (4) shows the load cases and load types that have been used for the analysis of the structure.

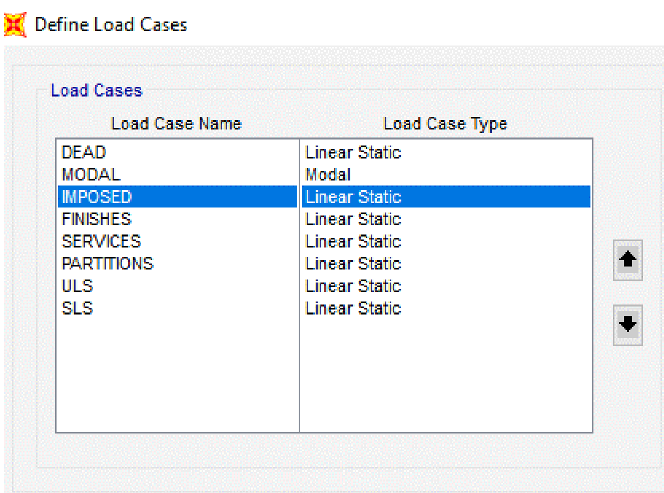


Figure 4. Load cases and types from SAP200

IV. RESULTS

A. *Load combinations*

Figure (5) Shows the load combinations for dead load, live load in different design codes. Through the study one combination from each code is maintained .

Figure 5. Values of DEAD &LIVE loads from different codes

B. *Selection of members*

Different codes specify different regions for calculating the resistance with different limits. Hence, when combining the actions and resistances of each sections, it is expected to have different sections depending upon the requirements. The table AS3600 [14] requires smaller sections while ACI318 [12] gives us large size of members compared to other standards. However, the sections depend upon the type of occupancy. Also, a small increase in the required section is observed as the DEAD and LIVE load increases.

C. *Steel Reinforcement*

Design cross sections for elements are obtained by trial and error procedure. Structural elements are grouped considering requirements for easy construction management. The following Figure (6) display total required reinforcement (R/F) for Six-storey building considered. The calculation shows that the required reinforcement varies considerably among the codes for specific element groups.

The structural elements are grouped in to two categories.

1. Skeletal (Beams & Columns)

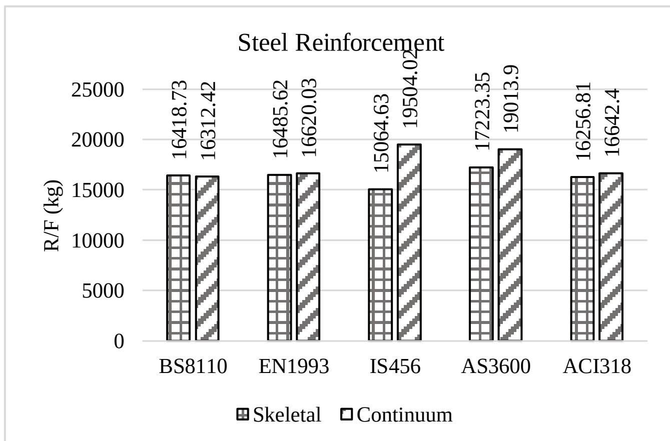


Figure 6. Required R/F for different elements

2. Continuum (Slabs ,Staircase and walls)

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Figure 9. Total Cost of concrete

TABLE 3. MEMBER DIMENSIONS AS SPECIFICATIONS PER VARIOUS CODES

	ELEMENT SIZES (mm)				
Members	***BS8110***	***EN1993***	***IS456***	***AS3600***	***ACI318***
Beam	300x400	250x400	300x400	300x300	300x400
	300x500	250x500	300x400	300x400	300x500
Columns					
Rectangular	300x300	300x300	300x300	300x300	400x400
	400x400	400x400	400x400	350x350	400x400
T-Type	400x400	400x400	400x400	350x350	400x400
L-Type	400x400	400x400	400x400	350x350	400x400
Slab	125	125	125	125	125
Lift core	200	200	175	175	200
Staircase					
Rise	175	175	175	175	175
Going	250	250	250	250	250

The following Figure (7) illustrates the required volume of concrete for different elements. Large amount of concrete is required for all the elements when we go for design with ACI 318[12] Code of practice. But that will cover all the design checks and other important requirements on the other hand AS3600[14] provides less amount of concrete volume.

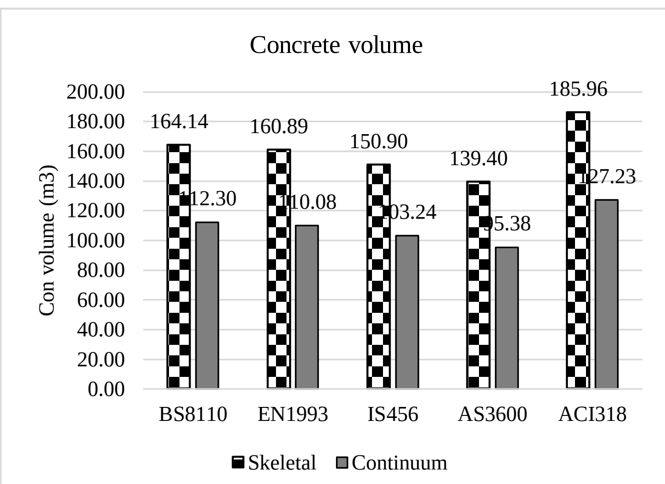

Figure 7.Total volume of concrete required for different elements

D. *Reinforced Concrete*

Overall requirements of concrete volume with the corresponding design codes are shown in the Figure (8). For a six-story medium rise building AS3600[14] gives a minimum amount of concrete volumes.it is mean it will provide smaller sections than ACI 318 [12]. All those sections are satisfied their basic design requirements. But it is not mean that always we should go for minimum value we should consider strength and other mandatory checks.

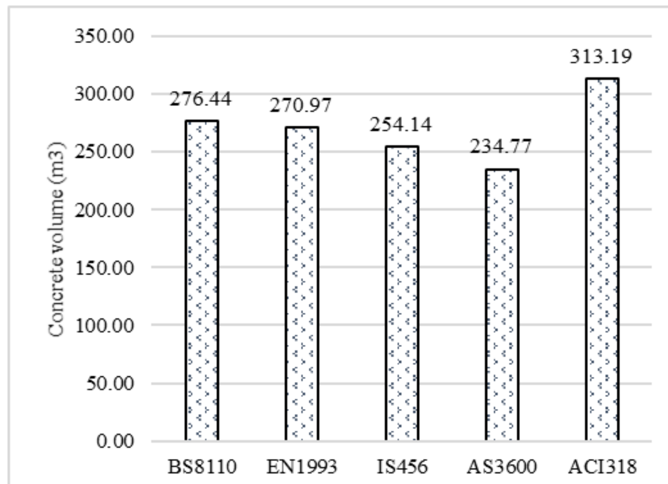

Figure 8. Total Volume of concrete required from different Codes

Figure 9. Total cost of concrete

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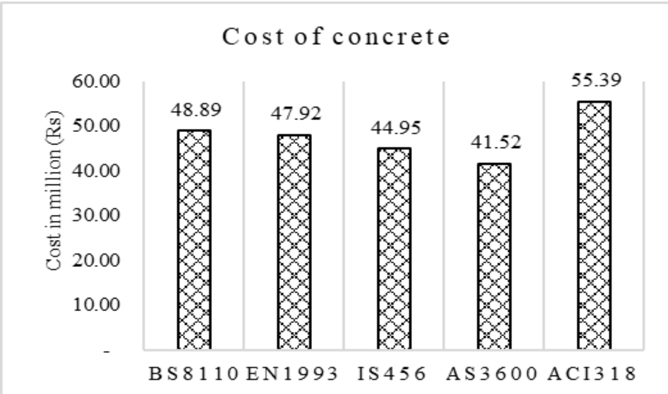
E. *Cost variation*

The following bar charts Figure (9) to Figure (11) display Total amount of cost considering cost of the Reinforcement and Concrete for Six-storey building. As shown in these figures we can see the price variation



with each code.

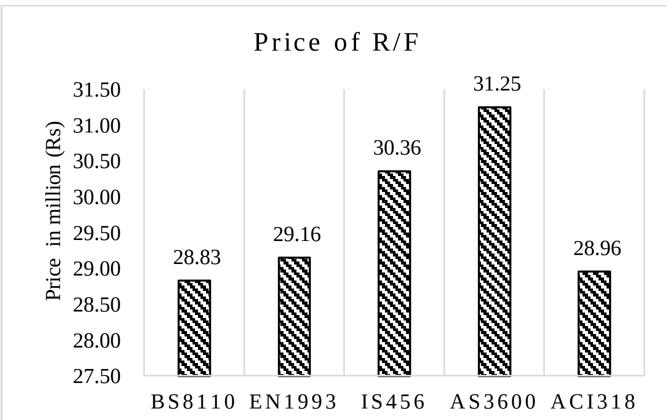


Figure 10. Total cost of reinforcement

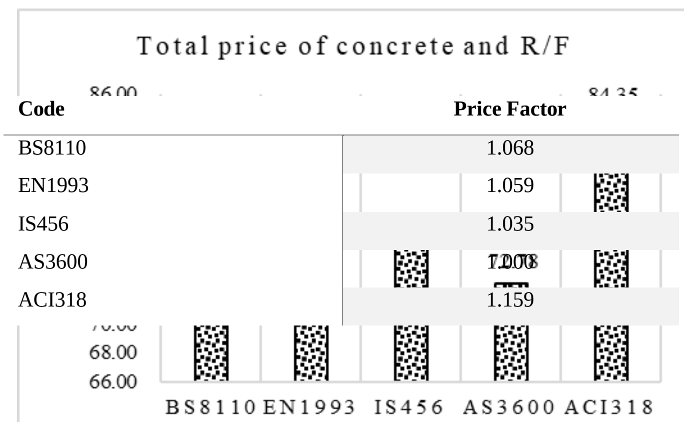


Figure11.Total cost of concrete & reinforcement

The following Table.4 gives us the price multiplication factor in terms of AS3600[14] code as the base prize. Because the total cost of the selected building is lower when we design with AS3600[14] Standards.

TABLE 4.TYPICAL PRIZE MULTIPLICATION FACTORS FROM DIFFERENT CODES

Code	Price Factor
BS8110	1.068
EN1993	1.059
IS456	1.035
AS3600	1.000
ACI318	1.159

F. *Service stress*

For the consideration of service stress, ultimate limit state design loads are used in the whole design and the strength of material is utilized in the full extent. In this method of design, after complete the ultimate limit design service stresses acting on structural members are calculated according to code of practice guidance. In fact, the whole structure during the lifespan may only experience loading stresses far below the ultimate state and that is the reason why this method is called service stress approach. under such scenario, the following Table(5) illustrates the service stress of steel in the different elements. The service stress equations are mentioned in the following table (5) by substituting $\frac{As\ (req)}{As\ (prov)}$ =1.0 .

TABLE 5. SERVICE STRESS IN DIFFERENT ELEMENTS WITH DIFFERENT CODES

DESIGN CODE		BS8110	EN1993	IS456	AS3600	ACI318
Equation that governs steel reinforcement service stress		$fs = \frac{5}{8}fy$	$fs = 0.6fy$	$fs = 0.58fy$	$fs = 0.55fy$	$fs = \frac{2}{3}fy$
Maximum service stress of steel R/f (N/mm^2)	*Skeletal elements*	312.5	300.0	290.0	275.0	333.3
	Continuum elements	312.5	300.0	290.0	275.0	333.3

We can see that ACI-3108 [12] yield higher values in service stress in steel than other design codes. Because the value of mortification factor of stress was 0.67. Figure (12) provides the comparison values of concrete volume before and after considering service stresses.

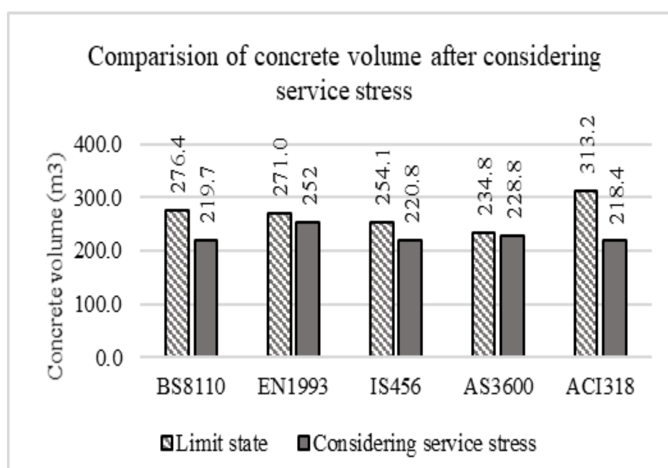


Figure 12. Comparison of concrete volume before and after considering service stress

Here we can see that there is reduce in concrete volume after considering service stresses in the ultimate limit design.it means we can go for smaller sections since service stresses are smaller than earlier. The following figure(13) provides total material cost variation after considering the service stress.

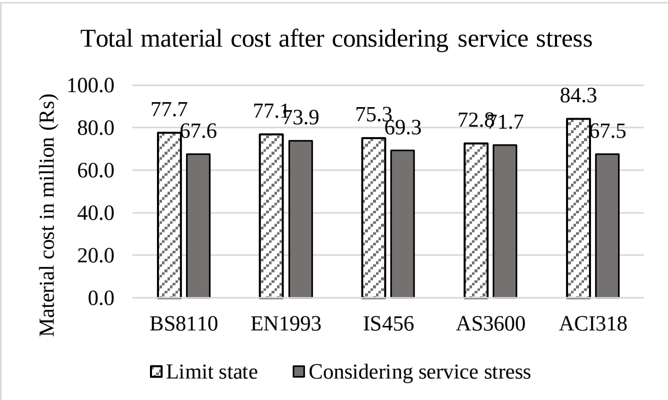


Figure 13. Comparison of total material cost after considering service stress

The following Table.5 gives us clear view of total material cost variation after considering service stress and the price multiplication factor in terms of ACI318[12] code as the base prize. Because the total material cost of the selected building is lower when we design with ACI318[12] after considering service stress.

TABLE 5.TOTAL MATERIAL COST AFTER CONSIDERING SERVICE STRESS ACORDING TO DIFFERENT CODES

Total material cost in million (Rs)

Design codes	*Limit state*	*Considering service stress*	*Difference*	*Price Factor*
BS8110	77.700	67.600	10.100	1.001
EN1993	77.100	73.900	3.200	1.094
IS456	75.300	69.300	6.000	1.026
AS3600	72.800	71.700	1.100	1.062
ACI318	84.300	67.500	16.800	1.000

V. CONCLUSION

Three building design codes and the corresponding codes for actions were considered. It was shown that combined effect of both DEAD & LIVE actions stipulated by different codes for better comparison. There are many similarities between design codes in concepts and design formulas. It is a common practice to use provisions according to a certain design code if it is missing from the local design code. However, not only this is illegal, but it could lead to unsafe or uneconomic designs as seen in the previous sections. Differences not only are observed in the safety factors used in calculating the Design sections, but they are also observed in the values of the Both Dead & imposed actions in different design codes. Large differences in live load intensities and load combination factors were noticed after comparing the values stipulated in different codes. Based upon the comparisons made for the considered cases in this study, the following conclusions could be drawn:

[1]. When variable actions are combined with permanent actions and considering the adverse and beneficial safety factors, some differences are still observed. Comparing the ultimate load combination of dead and live loads as defined by the studied codes, it was found that BS8110 & EN1992 yields the largest values for residential stairs and balconies. Meanwhile, the ACI318 yields the largest values for the residential floors.

[2]. Using actions from one code and resistances from another code could lead to unsafe designs. Different safety factors are considered which leads to large variations in the calculated resistance of sections and ultimate load combinations for the cases considered in the current study. Hence, a section might evaluate as safe according to a certain design specification and unsafe according to another.

[3]. The ACI318 standards generally yield the largest section dimensions with the heaviest values of steel reinforcement. But after considering service stress ACI 318 yield minimum sizes in all the members in contrast EN1992 gives largest sections.

[4]. Calculating the area of steel with respect to actual grade of concrete and grade of steel. Result showing that,
- For continuum elements Area of steel is maximum as per IS code and minimum as per BS Code.
- For skeletal elements Area of steel is maximum as per AS code and minimum as per IS Code.

[5]. Total Reinforcement required for the specific building is maximum when its designed by Australian standard and minimum yields by BS Standard. And the cost variation is about Rs.2.5 million.

[6]. Total Concrete Volume in terms of selected sections for the specific building is maximum when its designed by ACI 318 standard and minimum yields by AS3600 Standard. And the cost variation is about Rs. 3.9 million. But on the other hand, if we consider service stress ACI 318 produce smaller sections than other .and it is produce lowest material cost of the building. And we could save about 16.8 million (Rs) when considering service stress.

[7]. It is concluded that considering service would save around 20% of expenses on materials, comparing to the design using traditional limit state method ; and it is therefore recommended that for any design task, and whatever important the structure is, after the limit state method service stress should be considered in all the design codes.

Acknowledgment

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