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A Comparative Study of EC2 and BS8110 Beam Analysis and Design in a Reinforced Concrete Four Storey Building

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ABSTRACT

The analysis and design of the main structural elements in a four storey reinforced concrete building was undertaken using the two codes EC2 and BS8110 with the aid of the Prokon 32 suite of programmes. In respect of the main beams, the emphasis was on examining the bending moment diagrams for the critical continuous beam span for both codes before moment redistribution and after 10%, 20% and 30% redistribution in that order. It was found that for the negative bending moments at internal supports using the BS8110 values as baseline, the EC2 moments exceeded the BS8110 values by 0 to 8.5% at all levels of moment redistribution. However for the case of maximum span moments, the EC2 values lagged behind the BS8110 moments by about 4.5% to 9% for moment distributions up to 20%. At 30% distribution a lag of about 14.3% occurred in a specific case although this was felt to be an isolated example. An examination of the upper limit of the shear force envelopes at supports revealed that the BS8110 shears exceeded the EC2 ones by a margin of 2.4% to 5.4% in general. For the lower limit of the shear force envelopes the same trend was observed although the magnitude of BS8110's dominance was generally less than 2.5%. Such differences in shear were not necessarily consistent over all the supports however, and it was concluded that undue reliance should not be placed on the trend in shear variations with respect to both codes.

KEYWORDS: Codes, standards, design, moments, redistribution, shears.

INTRODUCTION

The structural design of most buildings worldwide is based on national and/or international codes of practice. These guide the engineer in the appraisal of the overall structural scheme, detailed analysis and design. Codes of practice are basically aids drawn up by experienced engineers and allied professionals, and they provide a framework for addressing issues of safety and serviceability in structural design. On the African continent very largely, national codes of practice have been primarily derived from the British standard BS8110-1997[1] and its predecessors. In several countries the British standard has been employed almost exclusively with the exception of variation of nationally determined parameters.

In the last three decades however an alternative set of codes to replace the British and other European national standards has been developed termed the Eurocodes (ECs). These comprehensive set of harmonized ECs for the structural and geotechnical design of buildings and civil engineering works were first introduced as Euronorme Voluntaire (ENV) standards, intended for use in conjunction with national application documents (NADs) as an alternative to national codes such as BS8110-1997 for a limited number of years. Subsequently these have been largely superseded by Euronorme (EN) versions with each member state of the European community adding a National Annex (NA) containing nationally determined parameters with the object of implementing the ECs as a national standard [2]. It should be stressed at this juncture however that the ECs have been introduced as part of the wider European harmonization process and not just simply to directly replace any national codes.

In the design of concrete structures, the relevant documents are EC0: Basis of structural design, EC1: Actions on structures and EC2: Design of concrete structures. The aims of these ECs are collectively to provide common design criteria and methods to fulfil the specified requirements for mechanical resistance, stability and resistance to fire, including aspects of durability and economy. Furthermore they provide a common understanding regarding the design of structures between owners, operators and users, designers, contractors and manufacturers of construction

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products. They also facilitate the exchange of construction services between member states of the European community as well as serve as a common basis for research and development in the construction sector. In addition they improve the functioning of the single market by removing obstacles arising from nationally codified practices. They also improve the competitiveness of the European construction industry [3].

EC2 or more precisely BS EN 1992, Eurocode 2: Design of concrete structures [4] was published in 2004. Since April 2010, EC2 has become the standard code in the United Kingdom for the design of reinforced concrete structures and the earlier BS8110-1997 has been withdrawn. However as previously noted, BS8110 still continues to enjoy a large degree of prominence on the African continent. The major exception to this is in the Republic of South Africa where there has been a major shift towards full embrace of the EC2 design philosophy as well as provisions. The foregoing dichotomy or state of affairs has added impetus to the need for the present study. It is anticipated that fuller embrace of EC2 as well as other ECs will have some impact on the design of all types of structures on the African continent. Consequently it is essential to publish the results of research and other data that narrow and focus the scope of the new design methods on specific elements that practicing are directly involved with. Hence a design aided investigation and comparative study is necessary to highlight points of convergence and difference between EC2 and BS8110. This has been achieved in the present study based on the analysis and design of a simple 4-storey building. Similar studies have been carried out in the United Kingdom [5, 6] and these were instrumental in the development of the present investigation.

In an attempt to enable a direct comparison between BS8110 and EC2 designs, the British Cement Association published the results of a joint study[7] dealing with the design of a 4-storey reinforced concrete building. To facilitate this objective a common concrete grade C32/40 was adopted. It was concluded that for the particular in-situ concrete office block chosen, there was very little difference between BS8110 and EC2 in the complexity of the calculations necessary or the final results obtained. Also a document prepared by the Concrete Centre [8] drew attention to the fact that a number of calibration studies had taken place and concluded that there were few fundamental differences between EC2 and BS8110. The report also highlighted an earlier study [5] which found that in general EC2 used in conjunction with the National Annex was not widely different from BS8110 in terms of the design approach. This latter study furthermore concluded that EC2 was less prescriptive and its scope was more extensive than BS8110, for example, in permitting higher concrete strengths. Hence the use of EC2 would permit designs not normally allowed in the United Kingdom and would give designers the opportunity to derive benefit from the considerable advances in concrete technology that had taken place.

An investigation [9] carried out on behalf of the Irish Government and the Irish Concrete Federation also found that for the specific structure investigated the differences in outcomes and costs using both EC2 and BS8110 were small. However it was stated that it would be necessary to investigate alternative structural sizes for a given loading and span condition in order to arrive at the optimum under each code. It was found that by carrying out one particular exercise along these lines, EC2 allowed a reduction in concrete element size in comparison to BS8110. Nevertheless the study stressed that the results were valid for the given spans, loads, etc. and might not necessarily be duplicated in other cases.

The present study is directed as noted earlier at a specific structural element – beams, in a simple four storey building. Its purposes are partly to sensitize and enlighten designers on the use of EC2, but more particularly, to highlight where possible some of the deviations of the EC2 results or provisions from BS8110. These objectives have been achieved by means of a comparative study. However a step by step detailed evolution of the design formulae for reinforced concrete beams in both codes has not been attempted here.

METHODOLOGY

Details of the selected building

The building chosen for the purpose of the present study was a four storey office complex of approximately 3.87 m floor height measured from the surface of the slab to suspended beam soffits. A roof and utility access panel was positioned above the 4th storey of the building. The latter also incorporated a basement of 3.0 m clear height that served as an underground parking facility. A schematic of a typical floor plan is shown in Figure 1. From this diagram the critical section based on the appraisal of the structural scheme and layout was identified as the building section that ran along grid line 6. Figures 2(a) and 2(b) are the critical sections of the building that were used for the purposes of frame and beam analysis respectively. The location of the critical continuous beam span can be taken at any level since the layout and schemes of the floor plans are identical throughout the building except at the roof level. Beam sizes were designed to suit the identified critical section of the building such that the beam sizes adopted from the design would be adequate at any other location in the building.

Method of analysis and design

The focus during the design of the building using EC2 and BS8110 code provisions was on the differences and/or similarities of main structural elements – beams, slabs and columns. However, only beams are reported in the present study. Also the building foundations were omitted here as these are the subject of a separate Eurocode which is beyond the scope of the current investigation. The computer package PROKON 32 [10, 11] was employed for the analysis and design on account of its widespread use amongst practicing structural and geotechnical engineers in Sub-Saharan Africa. It was felt that this fact alone should justify its reliability for the present study. However as a preliminary exercise, trial sections were analysed, designed and detailed manually to check the validity and correctness of the results obtained from PROKON 32.

Dead and imposed loads

In the building design, commonly used parameters by local practicing engineers such as that for imposed loads on floors for office buildings and durability and fire resistance requirements were made uniform for both EC2 and BS8110. Varied parameters were mainly those based on theories or principles of the codes such as the equations governing flexure at the ultimate limit state and shear. Differences in these principles might result in differences in the amount of load a common member dimension could carry, be it at service or the ultimate limit state. Consequently the amount of reinforcement required might also be affected. It has been opined that EC2, in common with other ECs, tends to be general in character and this might pose some difficulties in its initial use for design. Nevertheless for the present purposes there is no loss or wrong application in applying uniform factors to both code provisions for the building design. In this respect, uniform beam and column cross-sections were adopted because both EC2 and BS8110 show no substantial difference between preliminary span/effective depth ratios for beams (continuous beams in the present study) as shown in Table 1.

Table 1. BS8110 and EC2 basic span/effective depth ratios for rectangular beams

Support conditions	BS8110-1997	EC2 (O'Brien and Dixon [12])
Cantilever	7	7
Simply supported	20	18
Continuous	26	25
End spans of continuous beams	–	23

RESULTS

Bending moments

The bending moment profiles at 0% moment redistribution along the critical continuous beam span for both BS8110 and EC2 using PROKON 32 are shown in Figures 3(a) and 3(b) respectively. It is usually maximum span (or sagging) moments and maximum support (or hogging) moments that control the design of a beam section. Hence for comparative analysis, Tables 2(a) – 2(d) are presented to compare and contrast the moments at different levels of moment redistribution from 0% to 30%. The percentage difference shown in the tables was determined by keeping the BS8110 values as baseline. Hence a negative result would indicate a lag in EC2 magnitude of moment or shear at the particular location and vice-versa. In order to further illuminate the results shown, Figures 4 and 5 are presented for the cases of 10% and 30% redistribution respectively. It should be noted here that these graphs are not true representations of the bending moment profiles along the beam span, but rather serve to depict the bending moment dominance (or lag) in respect of either codes at the critical locations (approximately mid-span and at supports) along the beam. Graphs for 0% and 20% moment redistribution have been omitted.

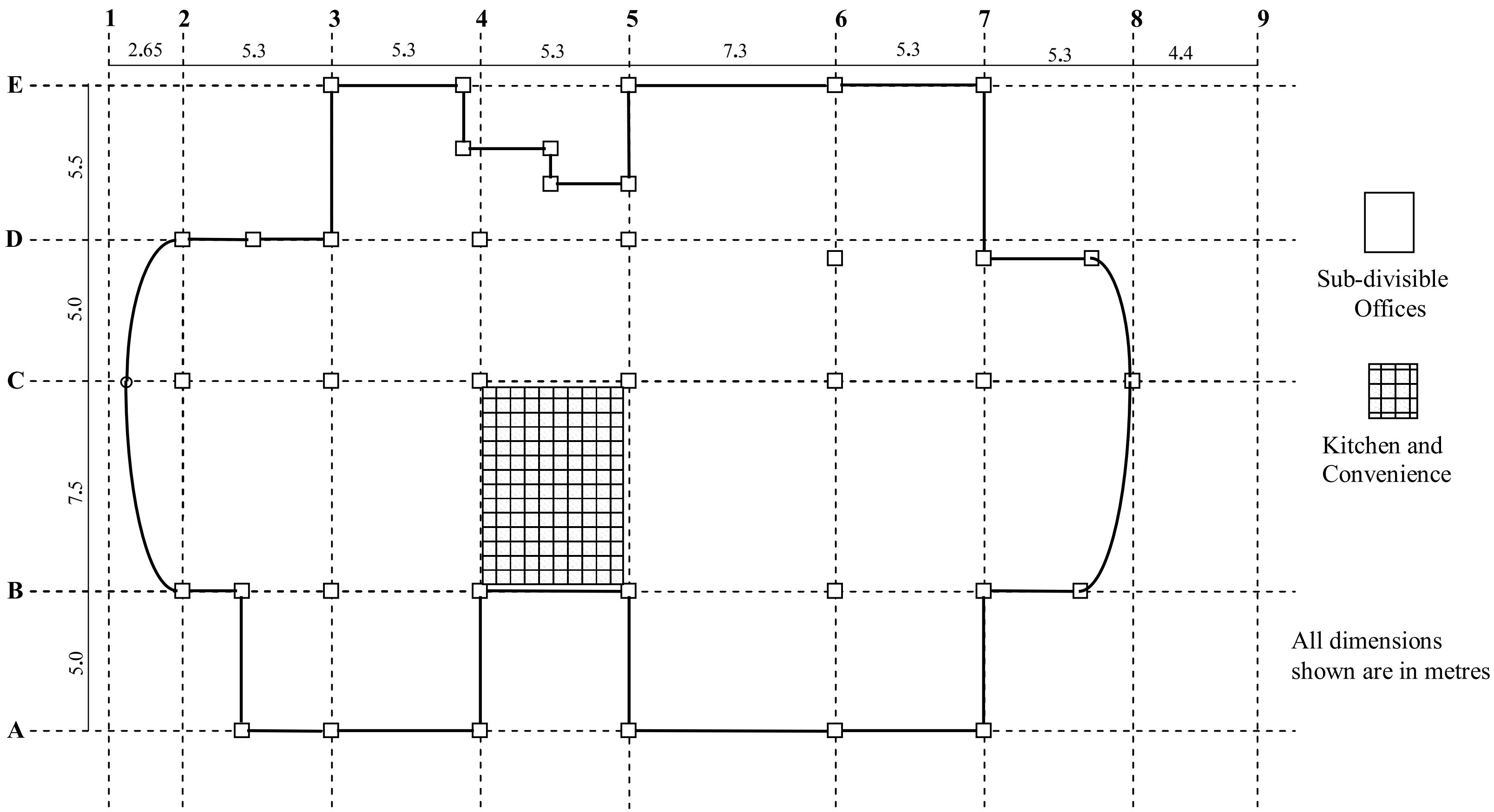

Figure1**.** Schematic of typical floor plan of building

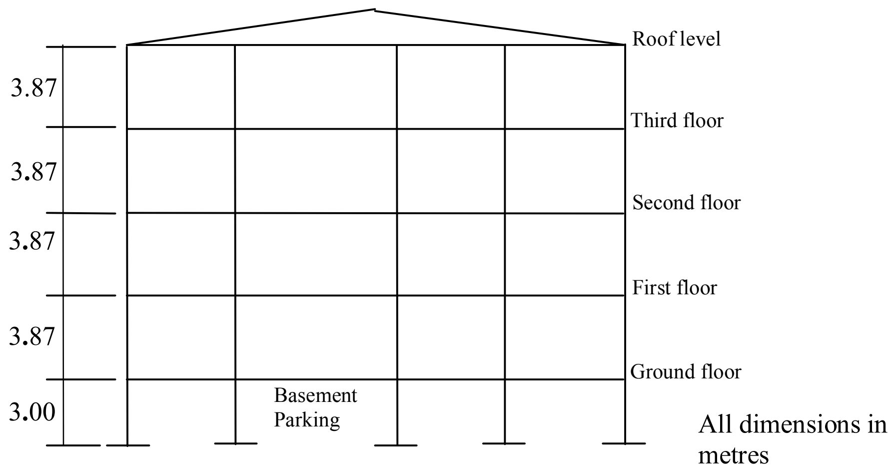

Figure 2(a). Critical section used for frame analysis

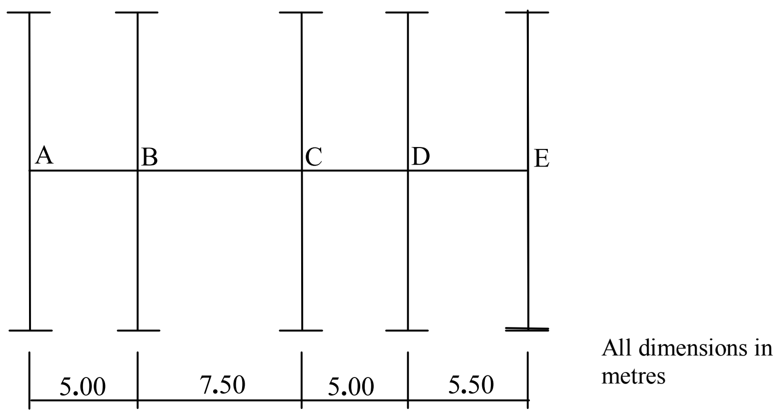

Figure 2(b). Critical section for beam analysis

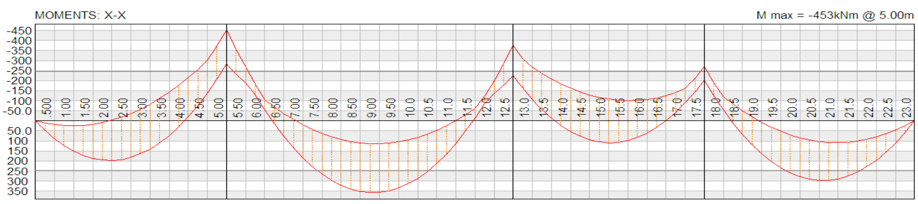

Figure 3(a). BS 8110's bending moment diagram for the critical continuous beam span.

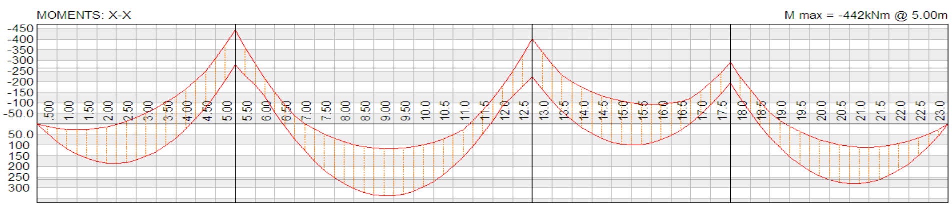

Figure 3(b). EC 2's bending moment diagram for the critical continuous beam span.

Shear forces

The shear force envelopes for the critical continuous beam section for both codes are shown in Figures 6(a) and 6(b). These envelopes were generated for the case of 0% moment redistribution. Tables 3(a) and 3(b) are presented to compare and contrast these shear values.

DISCUSSION

From Tables 2(a) – 2(d) and Figures 4 and 5, it is apparent that BS8110 tends to take moment dominance along the span both before and after moment redistribution. Conversely, EC2 yields higher values of hogging moments at the supports. This difference in trend is attributed to the different manner adopted by both codes to determine the design loads as well as the different approach taken in evaluating the worst load case for design (or pattern) loading. This can be readily appreciated from Table 4. It is apparent from Table 4 that for pattern loading both codes consider cases where firstly all spans, and subsequently alternate spans, are loaded with maximum design load. At this stage the load options are exhausted for BS8110, but in contrast, EC2 further considers a loading scenario where adjacent spans receive maximum design ultimate load whilst all other spans receive the minimum design dead load.

The current trend of moment difference appears sensible due to the fact that BS8110 applies larger partial safety factors to loads (or actions in EC2) at the ultimate limit state in contrast to EC2. For the latter, both γ_G and γ_Q the partial safety factors with respect to dead and imposed loads respectively are marginally lower compared with the BS8110 values. However for unloaded spans as seen from Table 4, γ_G is higher, reflecting a lower probability of variation in dead load [13]. For EC2 the use of the same γ_G throughout also reduces the effect of pattern loading, thus only marginally reducing span moments as opposed to the larger reduction experienced using BS8110 when $\gamma_G = 1.0$ is utilized for unloaded spans. Consistent with other observations [13], the difference in pattern loading may marginally increase EC2 support moments but reduce span moments as observed in Figures 4 and 5. This is logical when adjacent spans are loaded with maximum design load during the critical load case combination.

From Tables 2(a) – 2(d) the largest difference in moments between EC2 and BS8110 is 14.3%. This occurs along the internal span CD at 30% moment redistribution. However this appears to be an isolated case since all other differences are in the range 4.5% – 9%. At internal supports the EC2 moments generally exceeded the BS8110 values by 0% – 8.5% at all levels of moment redistribution. It should be noted from Figures 4 and 5 for redistributions of 10% and 30% respectively (and similar curves not reproduced in this study, for 0% and 20% redistribution) that the positions where BS8110 exhibits moment dominance over EC2 are consistent or at the same locations along the beam span, and vice-versa, at support locations. This consistency in trend regardless of the level of moment redistribution would suggest that there is not much difference in the moment distribution procedures adopted by the two codes.

With regards to shear, Tables 3(a) and 3(b) reveal that for the upper limit of the shear force envelopes, the BS8110 values exceeded the EC2 estimates by a maximum of 5.4%. Also for the lower limit of the envelopes, BS8110's dominance peaked at 2.4%. However it is obvious that there is no consistent trend, and hence, no undue emphasis should be placed on these results.

Table 2(a). Comparison of moments along the building's critical section (before redistribution)

		Left support moment (KNm)			**Maximum span moment (KNm)**			**Right support moment (KNm)**		
Span	Length (m)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)
AB	5.0	0	0	0.00	188	199	-5.53	-438	-448	-2.23
BC	7.5	-442	-453	-2.43	342	360	-5.00	-402	-376	6.91
CD	5.0	-402	-376	6.91	101	111	-9.01	-288	-266	8.27
DE	5.5	-288	-266	8.27	285	299	-4.68	0	0	0.00

Table 2(b). Comparison of moments along the building's critical section after 10 % moment redistribution

		Left support moment (KNm)			Maximum span moment (KNm)			Right support moment (KNm)		
Span	Length (m)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)
AB	5.0	0	0	0.00	188	199	-5.53	-394	-403	-2.23
BC	7.5	-394	-408	-3.43	340	361	-5.82	-361	-338	6.80
CD	5.0	-361	-338	6.80	102	111	-8.11	-259	-239	8.37
DE	5.5	-259	-239	8.37	285	299	-4.68	0	0	0.00

Table 2(c). Comparison of moments along the building's critical section after 20 % moment redistribution

		Left support moment (KNm)			Maximum span moment (KNm)			Right support moment (KNm)		
Span	Length (m)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)
AB	5.0	0	0	0.00	188	200	-6.00	-350	-362	-3.31
BC	7.5	-350	-362	-3.31	360	396	-9.09	-321	-301	6.64
CD	5.0	-321	-301	6.64	102	111	-8.11	-230	-212	8.49
DE	5.5	-230	-212	8.49	285	299	-4.68	0	0	0.00

Table 2(d). Comparison of moments along the building's critical section after 30 % moment redistribution

		Left support moment (KNm)			Maximum span moment (KNm)			Right support moment (KNm)		
Span	Length (m)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)	EC2	BS8110	Diff. (%)
AB	5.0	0	0	0.00	188	199	-5.53	-306	-313	-2.24
BC	7.5	-306	-313	-2.24	402	440	-8.64	-281	-263	6.84
CD	5.0	-281	-263	6.84	102	119	-14.3	-202	-187	8.02
DE	5.5	-202	-187	8.02	285	305	-6.56	0	0	0.00

Note: In Tables 2(a) – 2(d), the -ve % difference occurs where EC2 lags in moment dominance at locations along the span, usually, and vice-versa. Also "-ve" moments represent hogging moment over internal supports, whilst "+ve" moments represent sagging moments along the span.

Table 3(a). Comparison between EC2's and BS8110's magnitude of the upper limit of the shear force envelope at supports

		Shear at left support (KN)			Shear at right support (KN)		
Span	Length (m)	EC2	BS8110	Difference (%)	EC2	BS8110	Difference (%)
AB	5.0	192	203	-5.42	386	398	-3.02
BC	7.5	386	398	-3.02	-188	-188	0.00
CD	5.0	-188	-188	0.00	324	332	-2.41
DE	5.5	324	332	-2.41	-108	-106	1.89

Table 3(b). Comparison between EC2's and BS8110's magnitude of the lower limit of the shear force envelope at supports

		Shear at left support (KN)			Shear at right support (KN)		
Span	Length (m)	EC2	BS8110	Difference (%)	EC2	BS8110	Difference (%)
AB	5.0	53.9	50.8	6.10	203	203	0.00
BC	7.5	203	203	0.00	-371	-380	-2.37
CD	5.0	-371	-380	-2.37	179	180	-0.56
DE	5.5	179	180	-0.56	-244	-248	-1.61

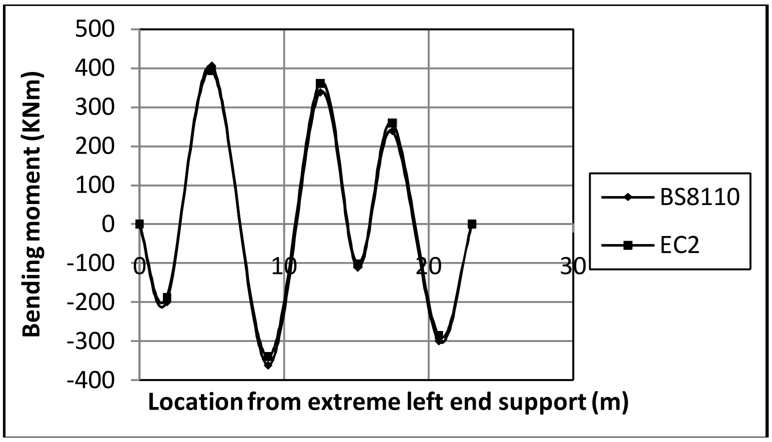

Figure 4. Comparison of bending moments along the building's critical section at 10 % moment redistribution

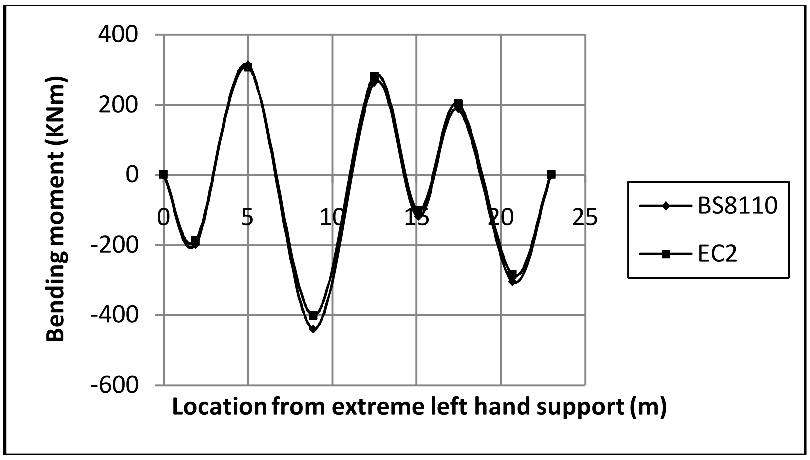

Figure 5. Comparison of bending moments along the building's critical section at 30 % moment redistribution

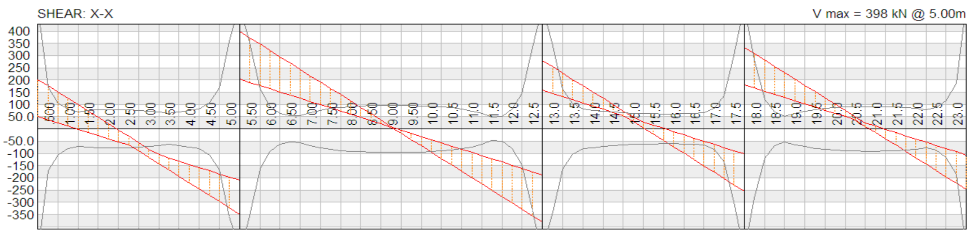

Figure 6(a). BS8110's shear force envelope along critical continuous beam span of building

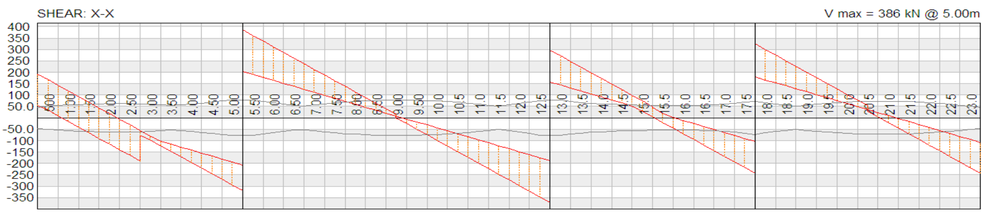

Figure 6(b). EC2's shear force envelope along critical continuous beam span of building

Table 4. Partial load safety factors applied during pattern loading according to BS8110 and EC2

	BS8110	EC2
Loaded spans	$\gamma_G = 1.4$; $\gamma_Q = 1.6$	$\gamma_G = 1.35$; $\gamma_Q = 1.5$
Unloaded spans	$\gamma_G = 1.0$	$\gamma_G = 1.35$ (as above)
Loading pattern	All spans + alternate spans	All +adjacent +alternate spans

CONCLUSIONS

The present investigation is part of a continuing one dealing with a comparative study of EC2 and BS8110 analysis and design provisions in respect of various structural elements. The emphasis here however, has almost exclusively been on beams. Based on the results of the study, the following conclusions have been reached.

(1) For the critical continuous beam section examined, the EC2 moments at internal supports generally exceed the BS8110 values by a range of 0% – 8.5%, at all levels of moment redistribution.

(2) With respect to maximum span moments in the continuous beam, the EC2 moments are lower than the BS8110 values by about 4.5% – 9%, for moment redistributions up to 20%. However at 30% redistribution the lag is about 14.3%, but this is felt to be an isolated case.

(3) The manner in which the partial load safety factors are applied as well as the procedures adopted in arriving at the worst loading scenario for pattern loadings in respect of the two codes contributes significantly to the difference in moments observed at the critical locations in both EC2 and BS8110.

(4) In the case of the upper and lower limits of the shear force envelopes, BS8110 estimates are generally higher by a range of 2.4% – 5.4%. However, some caution should be placed on these results for the trend is certainly not consistent.

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