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The Use of Concrete Design Codes across National Boundaries

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Summary

While code provisions relating to the built environment can easily be transposed across national boundaries, those relating to the social and especially natural environments can, and sometimes need, to be modified before such transposition can be effected. For example, before specifying for durability by strength as per BS 8110, a nation-wide survey should be carried out in order to correlate mix proportions with strength, since such correlations will not be universal, but rather depend on the raw materials used in different countries. Then again, the safety factors that are used for design could be modified for differing situations, with the socio-economic characteristics of developing countries suggesting that load safety factors be lower but material safety factors higher, in comparison with codes in more developed countries.

1. Introduction - Types of Environments

Many developing countries use concrete and other design codes that have been written in developed countries. In many cases, the former have been colonies of the latter. Code guidelines relating to the design of structures and elements for structural behaviour are based on the fundamental theories of structural mechanics. As such, aspects of the design for strength, serviceability and stability (i.e. aspects relating to the Built Environment) that are covered in the codes of one country can be used directly in another without undue difficulty.

However, there are two broad areas where transposition of codes could present difficulties. This is where codes impinge on (i) The Natural Environment (including raw materials and climate) and (ii) The Social Environment (including areas such as safety, quality and economy). This paper gives examples from both the above areas, highlighting one example from each. In most cases, it is the use of British codes in Sri Lankan practice that is described.

2. Influence of the Natural Environment

2.1. Effect of Raw Materials on Specifying Durability by Grade

One of the major changes introduced by the British concrete design code, BS 8110 (1), first issued in 1985, was the specifying for durability by grade and cover. Upto that time, CP 110 (2) had specified for durability by mix proportions such as water/cement ratio and cement content. Although the above change was made, it was still recognised that mix proportions were a more fundamental index of durability than was strength (3). The change in British practice was based on a survey described by Deacon and Dewar (4), where the strengths of OPC concretes that could be achieved in U.K. batching plants for various values of water/cement ratio and cement content were plotted; the grades required for durability were then based on strengths achieved by 96% of the plants. Hence, although durability is specified by grade (in Table 3.4 of BS 8110), it is recognised that mix proportions (which are also displayed in Table 3.4) are the primary indices of durability (3). This is why BS 8110 (1) allows the grade to be reduced by a step of 5 (for OPC concretes) without any penalty of higher cover, if a checking regime establishes that the mix proportion requirement for the higher step is in fact being met by the concrete being supplied. The main reasons for the British change to specifying for durability by grade were (i) the ease by which strength could be monitored and (ii) the resolution of concrete mix design problems that arose when independently chosen grades had to be designed with mix proportions that also had to satisfy durability constraints (4).

The above change, in itself would not have constituted a problem for using BS 8110's Table 3.4 in Sri Lanka. However, British cement strengths had increased significantly and their ready mixed concrete production improved tremendously by the early 1980s (5). This meant that even low cement contents and high water/cement ratios resulted in fairly high grades of concrete - in fact the lowest grade of concrete in Table 3.4 (BS 8110) is grade 30, whereas Sri Lankan practice largely comprised grade 20 and grade 25 concrete.

A study was carried out by the author (6) to compare the strengths obtained in Sri Lankan batching plants located in the capital city of Colombo with those obtained on a major hydropower construction project (Mahaweli headworks, where very careful batching was done) for various cement contents and water/cement ratios. These were also compared with the U.K. values from Deacon and Dewar (4). Some results are presented in Tables 1 and 2.

It can be seen that although the Mahaweli strength results are fairly close to the U.K. ones, the Colombo results are around 10 N/mm^2 lower than the U.K. ones. Closer examination (6) showed that the U.K. cements had higher finenesses and C_3S percentages in their range (Table 3), which would tend to increase 28 day concrete strengths. At the same time, the Mahaweli concretes had better aggregate gradings (Table 3). This is reflected by (i) a higher ratio of coarse to fine aggregate, together with a lower ratio of larger size to smaller size fraction within the coarse aggregate (this type of grading will eliminate gaps between aggregates, leading to better compaction of the concrete) and (ii) a higher proportion of ultrafines (particles less than 0.25 mm) in the mix, which once again will eliminate gaps between aggregate and even lead to a reduced water demand. Both the above will result in higher strengths for given cement contents and water/cement ratios.

Table 1 - Selected comparison of 95% 28 day cube strength values (N/mm²) vs. w/c ratio

Source	Water/cement Ratio						
(Author / Concrete)	0.75	0.70	0.65	0.60	0.55	0.50	0.45
Deacon & Dewar (4) / U.K.			40	45	50	55	60
Dias (6) / Mahaweli, S.L.	34	37	40	44	50	58	
Dias (6) / Colombo, S.L.	20	23	27	33	41		

Table 2 - Selected comparison of 95% 28 day cube strength values (N/mm²) vs. cement content

Source	Cement Content (kg/m³)									
(Author / Concrete)	250	275	300	325	350	375	400	425	450	475
Deacon & Dewar (4) / U.K.		40	45	50	55		60			
Dias (6) / Mahaweli, S.L.			46	48	50	53	56	59	61	64
Dias (6) / Colombo, S.L.	29	33	36	39	42	46	49			

Table 3 - Comparison of cement properties and aggregate grading

Concrete Type	U.K. (5,7)	Mahaweli	Colombo
Cement Fineness (m²/kg)	287-390	310-338	311-343
7 day Mortar Compressive Strength (N/mm²)	43.6	40.0-42.1	40-50
C_3S Percentage in Cement	45-64	48.0-56.7	47.8-58.0
Coarse/fine aggregate ratio		1.32-2.15	0.96-1.54
Larger/smaller size fraction in coarse aggregate		1.47-2.86	4.0
Fines<0.25 mm in Fine aggregate		24.5	5
Fines<0.25 mm in Total aggregate		7.78-8.78	2.30-2.55

Table 3 shows therefore that the Colombo plants are unable to achieve higher strengths for given cement contents and water/cement ratios, because they neither have very high quality cements nor optimised aggregate gradings - i.e. good quality raw materials. If the raw materials for the Colombo plants are to be used to produce the BS 8110 durability grades, very high cement contents would be required; this in turn could cause thermal and shrinkage cracking that would impair the very durability that is being sought.

This problem can be resolved by suggesting lower grades in BS 8110's Table 3.4, grades that have been arrived at on the basis of a survey of Sri Lankan batching plants (6). A similar approach has been taken by the Irish Republic as well (8).

In the above context, Eurocodes are an interesting development. They may in fact be more relevant for developing countries, because the countries that form "Europe" themselves are fairly disparate in economic status and level of development. As such, it will not be possible to maintain throughout Europe the same practices as for example in Germany and the U.K., and this would be reflected in the Eurocodes. An example of this is the reverting back to water/cement ratio and cement content in specifying for durability (9).

Another consideration in this regard is the very definition of appropriate environmental conditions, which will also vary from one country to another. An attempt has been made (10) to "compare" the 5 durability environments in BS 8110 with the 9 environments defined in EC2.

2.2. Other Influences of the Natural Environment on Design Practice

The ambient temperatures in a country will influence thermal effects in concrete. The heat of hydration temperature rise (T_1) values given in BS 8007 (11), i.e. the concrete design code for water retaining structures, correspond to the U.K. based ambient temperature of 15°C. As Sri Lankan ambient temperatures are another 15°C higher, at least some of these T_1 values will have to be increased appropriately; perhaps even to the extent of 0.5°C for every °C change in ambient temperature (12).

Another area where local values are appropriate is the use of relevant wind load values. Basic wind speeds in Sri Lanka can be obtained from a design guide (13) developed in the wake of a cyclone on the East coast in the late 1970s.

3. Influence of the Social Environment

3.1. Effect of Safety Factors on Design Economy

The differences in the socially accepted levels of safety across national boundaries could also influence design practice. This is reflected in the safety factors (generally the load safety factors) that are adopted. For example, the partial safety factors for loads in Eurocode 2 (14), which is the Eurocode for concrete design, are 1.35 for dead and 1.5 for imposed loads. These are less than the factors in BS 8110 (which has 1.4 for dead and 1.6 for imposed loads).

The results of a comparison (10) between the BS 8110 and EC2 bending moments in a multi-bay braced portal frame structure are given in Table 4. Apart from the above mentioned difference in load safety factors, the EC2 code specifies the "adjacent spans loaded" combination in place of BS 8110's "all spans loaded" combination. This causes higher beam moments at interior supports for EC2 analyses; apart from this, however, EC2 analyses give lower moments in both beams and columns.

Table 4 - Comparison of portal frame moments from analyses as per BS 8110 and EC2 (10)

Element	Location	Comparison
Beams	End support	EC2 values 4-9% below BS 8110 values
	Near middle of first span	EC2 values 4-11% below BS 8110 values
	First interior support	Very similar (+ or - 5%)
	Near middle of other spans	EC2 values 12-20% below BS 8110 values
	Other interior supports	EC2 values up to 15% above BS 8110 values
Columns	Outer column	EC2 values 4-9% below BS 8110 values
	Interior columns	EC2 values up to 50% below BS 8110 values

If it is perceived that codes are too conservative, the industry could begin to reduce the levels of safety, especially for construction in the informal sector. For example, when the Sri Lankan industry was using CP 110 (2), a limited questionnaire survey (15) was carried out among three classes of construction industry personnel, namely Construction engineers working for contractors (Class A), Site engineers working for consultants (Class B), and Design engineers working for consultants (Class C); each of the above was also categorised with respect to experience in the construction industry, i.e 0-10 years (Category 1) and over 10 years (Category 2). They were asked to give their design solutions (in terms of slab thickness and spacing of 10 mm dia. high yield reinforcement) for a continuous one way slab system of spans 3.5 m and 5.0 m for both domestic and office buildings.

The domestic buildings were to be for their own dwellings, while they were to design the office buildings as part of their professional practice. The effective safety factors they were using could be back-calculated by assuming a dead load allowance of 1.5 kN/m^2 for partitions and finishes, and characteristic imposed loads of 1.5 kN/m^2 and 2.5 kN/m^2 for domestic and office buildings respectively.

The class- and category-wise means and also overall means for effective safety factors are shown in Table 5. This indicates that the overall mean effective global safety for one way slabs in domestic buildings was 1.6, compared to the CP 110 value of around 1.7; however, the latter value was in fact maintained or even exceeded for one way slabs in office buildings. The safety factors employed for 5.0 m spans was less than that for 3.5 m spans; it appears here that some safety was being sacrificed for economy. Also, it appears that the lower safety factors were being used by design engineers and those with over 10 years of experience - i.e. people who were presumably well aware of the implications of their actions. It must be emphasised, however, that a wider survey is required to corroborate the above trends, as there were only 18 respondents to the questionnaire.

Table 5 - Mean effective global safety factors from survey of one way slab designs (15)

Structure Type	Class A	Class B	Class C	Category 1	Category 2	Overall
Office - 3.5 m span	2.125	2.063	1.874	1.983	1.980	1.98
Domestic - 3.5 m span	1.973	1.858	1.616	1.758	1.770	1.76
Office - 5.0 m span	1.792	1.701	1.350	1.608	1.448	1.57
Domestic - 5.0 m span	1.742	1.598	1.150	1.450	1.379	1.42
Office (overall)	1.958	1.882	1.874	1.983	1.714	1.77
Domestic (overall)	1.857	1.728	1.397	1.611	1.575	1.60
3.5 m span (overall)	2.049	1.961	1.745	1.870	1.875	1.87
5.0 m span (overall)	1.767	1.649	1.256	1.533	1.414	1.49
All types	1.91	1.81	1.51	1.71	1.65	1.66

3.2. Other Influences of the Social Environment on Design Practice

The above discussion suggests that slightly lower load safety factors could be appropriate for developing countries. On the other hand, reductions in materials partial safety factors should be avoided, because construction practices, including the procurement or production of construction materials, are likely to be less stringent in developing countries. For example, the partial safety factor for reinforcement in BS 8110 has recently been reduced from 1.15 to 1.05, no doubt because of improved production practice in the U.K. This however would be clearly inadvisable for a country such as Sri Lanka to adopt, because of the wide variety of imported steels (with widely varying properties) that are used there.

Imposed loads could also vary from one country to another, and statistical information on live loads is scarce in all countries. A preliminary survey of office buildings in Sri Lanka yielded a value of 2.3 kN/m^2 for the equivalent uniformly distributed imposed load for office buildings (15) - the value in the British loading code is 2.5 kN/m^2 (16).

4. Conclusions

The built environment, natural environment and social environment have been identified as three environments that are addressed by design codes. Code provisions relating to the built environment can easily be transposed across national boundaries. Those relating to the social and especially natural environments can, and sometimes need, to be modified, after carrying out national surveys. For example, this paper has described a proposal for reducing the BS 8110 concrete durability grades by 5 for Sri Lankan practice, after a batching plant survey; and how practising engineers in Sri Lanka indicated their preference for the slightly reduced global factor of safety of 1.6, compared to the CP 110 provision of around 1.7, for the design of one way slabs. Other areas that may require modification have also been identified, namely heat of hydration temperature rise values, basic wind speed values, imposed load values and material partial safety factor values.

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