Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 81 (1999)

Artikel: Importance of workmanship in concrete construction
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DOI: https://doi.org/10.5169/seals-61442

Importance of Workmanship in Concrete Construction

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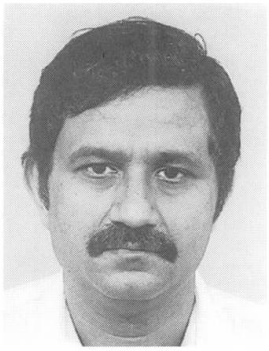

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Summary

The paper discusses the importance of workmanship in concrete construction and in particular focuses attention on Part II (Materials & Construction) of the Draft Concrete Model Code, where a sub-section on workmanship is devoted to all major aspects of concrete construction including formwork, reinforcement, materials, mixing, placing and curing of concrete.

To ensure good workmanship, it is recommended that dimensional tolerances are specified for all structural elements and these are checked for compliance during different phases of construction. The paper gives some tolerance limits commonly accepted in Australia for different types of structural elements, reinforcing bars and in the mixing and placing of concrete. It is recommended that these be adopted and used in the Concrete Model Code.

1. Introduction

In any civil engineering construction project, dimensions will seldom, if ever, equal exactly to what is specified or shown on the drawings. The deviations from the specified dimensions result from a combination of several factors, but it is seen that these are generally related to poor workmanship and lack of quality control measures exercised on site. If the recommended materials are used in construction and proper inspection procedures are followed, then the dimensional variations in the members could be significantly reduced and better workmanship would result.

With the availability of several computer packages these days, design of most civil engineering structures can be done to a high degree of accuracy and designers' with their good understanding of material properties can specify the most appropriate material suited for a particular end use, but unfortunately, they do not have any control over workmanship, as it depends on the skills of the workers and the quality control measures exercised on site. An accurate and a precise design, coupled with the use of excellent building materials cannot be transformed into a good building structure, if the workmanship is not proper. Moreover, if the standard of workmanship is poor, finished structure, apart from presenting an unpleasant appearance is not likely to perform according to its expected behaviour. To overcome the problem of dimensional variability and workmanship, it is suggested that instead of only specifying the dimensions for structural elements, acceptable limits of tolerance for members should also specified in the structural drawings. In some countries, this practice is already in existence and

relevant Codes (1) have been developed and are available for compliance by builders and contractors. However, it has been observed that the standard of workmanship and dimensional variations are not a real threat in most developed countries, because well documented inspection procedures are already in place and inspection in all phases of construction is carried out as a matter of routine. However, the situation in developing countries is different, where quality and workmanship are not given due regard in many cases.

2.0 Essential Requirements for Quality and Workmanship

2.1 Inspection and Supervision

To achieve a high standard of workmanship in concrete construction, it is essential that proper inspection and supervision procedures are followed in all phases. A proper and a timely inspection will ensure that all design requirements laid down in the specifications and on the structural drawings are achieved in construction. The inspection and supervision work entails regular checks on all phases of the work in progress, as well as on the completed portions of the structure, to assess their compliance to the specifications.

Apart from the dimensional and alignment checks, site inspection also includes an examination of the building materials and formwork. In addition, site supervisors are also expected to carry out regular checks on mixing, placing, compacting and curing of concrete to ensure that proper quality of concrete is maintained in all phases of construction.

To have a tighter control on the quality of construction, the site supervisor should have an authority to refuse the use of materials which do not conform to the specifications and ones which are likely to result in improper construction. He should have an authority to stop any work in progress which is not in accordance with the approved plans and specifications for the job. The supervisor should also have the power to order for the removal or repair of faulty construction or for any construction performed without an inspection.

2.2 Workmanship in Formwork

The accuracy which can be achieved in concrete construction depends on the skills and workmanship exercised in the fabrication of formwork, because fresh concrete does not have a shape or configuration of its own, but acquires the shape and size of the formwork, after it sets and hardens. Therefore, it is essential that formwork must be built to correct dimensions and shape. It is also essential that the formwork has sufficient rigidity to maintain its shape and dimensional integrity under different types of construction loads. In addition, it should be stable and must be strong enough to align large members in position.

To achieve a proper shape, size and alignment of concrete elements, it is necessary that dimensions such as width, height and length of the formwork are calculated precisely, so that the dimensions of the finished member are within the acceptable limits of tolerance. It should be noted that no dimensional tolerance limits are specified in the Draft Concrete Model Code and to achieve any reasonable standard of construction in most developing countries, it will be more than desirable to have such limits. Some of the ACI Committee 347 recommended limits of tolerance for different structural elements as referred to in (2) are given in Table 1. A similar set of tolerance limits are also available for the footings of columns, piers, walls, buttresses and other structural members. In Australia, dimensional tolerances and permissible surface tolerances for

surface finishes are specified in AS 1509 (3) and AS 1510, Part 1, (4) respectively. Similar, tolerance limits specified in the United Kingdom are given in BS 3626 (5).

Table 1

Acceptable tolerances for various structural elements

Structure	Tolerance
1. Variation in cross-section dimensions of columns, beams, buttresses, piers and similar members	- 0.25 in (6mm) + 0.5 in (12mm)
2. Variation in the thickness of slabs, walls, arch sections, and similar members	-0.25 in (6mm) +0.5 in (12mm)
3. Variations of dimensions to individual structure	1.25 in (32mm) in 80ft or more features from established positions (twice this amount for buried construction
4. Variation from the plumb from the specified batter or from the curved surfaces of all structure, including lines and surfaces of columns, walls, piers, buttresses, arch sections, vertical joint grooves and visible arrisses	0.5 in. (12mm) in 10 ft 0.75in. (19mm) in 20 ft 1.25in. (31mm) in 40 ft or more (twice above amounts for buried construction)
5. Variation from the level or from the grades indicated on the drawings in slabs, beams, soffits, horizontal joint grooves and visible arrises	0.25 in. (6mm) in 10 ft 0.50 in. (12mm) in 30 ft or more (twice above amounts for buried construction).

A comparison of the dimensional tolerances acceptable in the US (2) , Australia (3) and the U.K. (5) indicates only a marginal difference in some structural elements and in most cases, the values are identical. However, it is to be noted that no acceptable limits are not discretely specified in many Asian countries and judgement of the site engineers is usually relied upon. However, some Asian countries do mention in the contract documents that dimensions of the finished members should be within the tolerance limits given in the British Standard (5).

It is to be noted that fabrication of an excellent and a precise formwork, will also not necessarily ensure good surface finish and workmanship because, small errors in the assembly of formwork have been seen to lead to catastrophic failures. In some cases, timber formwork have failed because adequate number of nails were not provided during the assembly of the components while in other cases, proper tightening of nuts and locking devices was not carried out. Some of these problems can be overcome, if proper inspection and safety checks are carried out on site as a matter of routine.

2.3 Inspection of Reinforcement Bars before Concreting

To ensure proper quality of concrete construction, it is recommended in the draft Concrete Model Code that the surface of the steel bars should be free from mud, oil or grease or non-metallic coating and loose rust. These appear to be an ideal set of conditions for reinforcement bars and ones which are difficult to achieve in practice because, bars normally have a coat of natural rust on them. Moreover, steel is generally stored on site and close to the excavated ground and therefore, bars invariably pick up rust and are often covered with mud as well. A more realistic clause in the Model Code should be: 'the site supervisor should ensure that loose rust and mud are brushed off from the reinforcement before placement and he should also check that rusting has not caused excessive pitting or loss of cross-section of the reinforcement'.

To ensure good workmanship, it is essential to check that the reinforcement is fixed as shown in the structural drawings and is supported by approved concrete, metal or other chairs. The maximum permissible tolerances on fixing reinforcement in structural elements in accordance with the Australian specifications AS 1480 (6) are given in Table 2.

Table 2

Maximum permissible tolerances on fixing reinforcement

Location of reinforcement or dimension to the end for which the tolerance applies	Tolerance
In any member, the tolerance measured in the direction of 'd' where the overall depth or thickness, D in the same direction is	
(a) up to 300 mm	± 5mm
(b) more than 300 mm and up to 450 mm	± 10mm
(c)more than 450 mm and up to 600 mm	± 15mm
(d)more than 600 mm	± 20 mm
At that end of a bar, or at the outside edge of a bent bar where the location is	
(a) controlled by concrete cover	± 15mm
(b) not controlled by concrete cover	± 50mm
The specified lateral location of any one bar of slab or wall reinforcement, in the plane of the reinforcement, or of any one fitment, in the direction of the specified spacing	± 0.25 times the specified spacing

In addition to the above tolerances, the Australian specification also gives both the minimum and the maximum distance between parallel reinforcement bars. The minimum distance between any two bars is specified to permit proper placement and compaction of concrete, while the maximum spacing is specified to ensure adequate performance of the reinforced concrete member.

For the UK, the BSI publication - BS 4466 (7) sets out preferred shapes and gives guidance on cutting and bending tolerances of reinforcing bars, while the British Code of Practice BS 8110 (8) contains recommendations for cover to bars and permissible deviations.

It is to noted that workmanship in the placing of reinforcement bars for a concrete member is judged from the uniformity of spacing between the bars and the care exercised in securing the bars in position to ensure that they do not displace when the concrete is poured and compacted. In addition, it is important to ensure that the bar placing tolerances do not add with the tolerances of the formwork to leave steel with insufficient cover. While inspecting the layout and fixing of the reinforcement in a formwork, it is also necessary to check and ensure that the minimum concrete cover requirements for different exposure conditions are met.

2.4 Workmanship in Concreting

Workmanship in concreting is judged from the condition and tolerances of the finished surface. A good surface finish is one which is free from surface cracking and which does not have an unsightly differences in texture and colour, especially in exposed work. All these qualities can be achieved in a concrete element, only if, proper quality control measures are taken in all operations of concrete construction such as batching, mixing, placing, compaction, finishing and curing.

To have uniformity in concrete from one batch to the other, it is necessary to ensure that materials used on site are procured from the same sources and specified proportions of constituents are maintained while for the mixing process, the mixing time has to be adjusted to ensure that ingredients get uniformly distributed within the mass of concrete. The uniformity requirements for a concrete mix and the extent of variations permitted in Australia as specified in the Australian Concrete Inspection Manual (9) and a set of recommended values are reproduced in Table 3.

Table 3

Requirements for uniformity of concrete

Test	Requirement, expressed as maximum permissible difference between results of tests of samples taken from two locations in concrete batch
Slump	
If average slump is 80mm or less	25 mm
If average slump exceeds 80 mm	40 mm
Air content, percent by volume of concrete	1.0
Coarse-aggregate content, portion by mass of each sample retained on 4.75mm test sieve percentage	6.0

In the concreting process, placing and compaction operations are most important and therefore demand careful attention and proper inspection. Proper checks during these operations will not

only prevent segregation of concrete but will also avoid displacement of forms and reinforcement, secure a good bond between layers, minimise shrinkage cracking and result in a structure with a good surface finish. While compacting with mechanical vibrators, it is necessary to check that vibrations are not carried out for prolonged periods at any one position because they often lead to honeycombing and lack of homogeneity in concrete.

3.0 Conclusions

Dimensional variations are inherent in all construction processes and are related to the level of workmanship and control exercised on site. Fine tolerances require a higher level of workmanship, regular inspection schedules and tighter controls, while a lower level of workmanship will result in higher tolerances.

To achieve a high standard of workmanship, the supervisor and his staff should be familiar with acceptable dimensional tolerances for different types of work in general, and specifically with any tolerances the designer has specified for a particular construction. It is recommended that dimensional tolerance limits are clearly stated either on the construction drawings or in the specifications.

Accuracy in shape, size and alignment of concrete elements depends on the accuracy to which the formwork is built and assembled on site. Small errors in the assembly of formwork have been seen to lead to catastrophic failures.

The quality of workmanship in the placing of reinforcement bars in a concrete member is judged from the uniformity of spacing between the bars and the care exercised in securing the bars in position.

Finally, to have an acceptable quality of construction, it is essential that dimensional checks and workmanship control measures are inspected in all stages of constructional activity, including the fabrication of formwork, placing of reinforcement, batching , mixing placing, compaction and curing of concrete.

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