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COMPACTION of Concrete

SCOPE

This data sheet discusses the benefits of compaction of concrete and provides information on the techniques for undertaking the process on site.

INTRODUCTION

Compaction is the process which expels entrapped air from freshly placed concrete and packs the aggregate particles together so as to increase the density of concrete. It increases significantly the ultimate strength of concrete and enhances the bond with reinforcement. It also increases the abrasion resistance and general durability of the concrete, decreases the permeability and helps to minimise its shrinkage-and-creep characteristics.

Proper compaction also ensures that the formwork is completely filled – ie there are no pockets of honeycombed material – and that the required finish is obtained on vertical surfaces.

When first placed in the form, normal concretes, excluding those with very low or very high slumps, will contain between 5% and 20% by volume of entrapped air. The aggregate particles, although coated with mortar, tend to arch against one another and are prevented from slumping or consolidating by internal friction.

Compaction of concrete is, therefore, a two-stage process **Figure 1**. First the aggregate particles are set in motion and slump to fill the form giving a level top surface. In the second stage, entrapped air is expelled.

It is important to recognise the two stages in the compaction process because, with vibration, initial consolidation of the concrete can often be achieved relatively quickly. The concrete liquefies and the surface levels, giving the impression that the concrete is compacted. Entrapped air takes a little longer to rise to the surface. Compaction must therefore be prolonged until this is accomplished, ie until air bubbles no longer appear on the surface.

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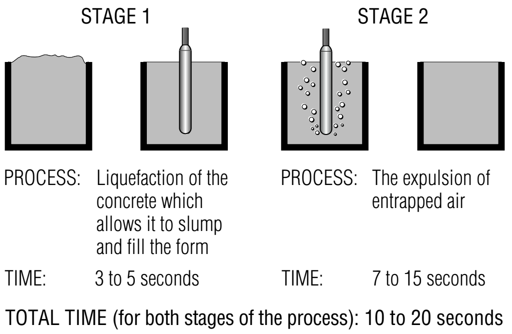

Figure 1: The process of compaction

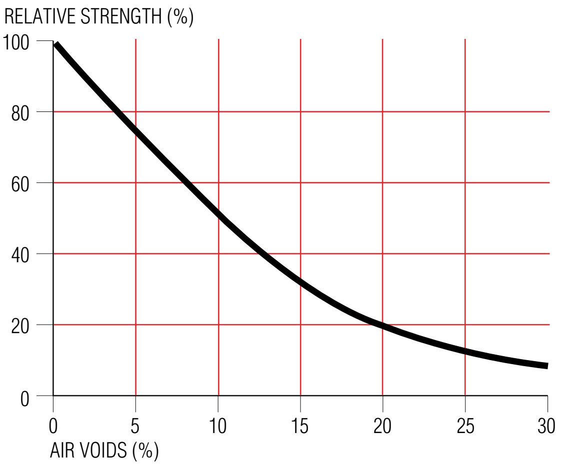

Figure 2: Loss of strength through incomplete compaction

EFFECT ON HARDENED PROPERTIES

As may be seen from **Figure 2**, the effect of compaction on compressive strength is dramatic. For example, the strength of concrete containing 10% of entrapped air (air voids) may be as little as 50% that of the concrete when fully compacted.

Permeability may be similarly affected since compaction, in addition to expelling entrapped air, promotes a more even distribution of pores within the concrete, causing them to become discontinuous. This reduces the permeability of the concrete and hence improves its durability.

The abrasion resistance of concrete surfaces is normally improved by adequate compaction. However, excessive vibration, or excessive working of the surface, can cause an excessive amount of mortar (and moisture) to collect at the surface, thereby reducing its potential abrasion resistance. In flatwork therefore, a careful balance is required to expel entrapped air without bringing excessive amounts of mortar to the surface of the concrete.

METHODS AND EQUIPMENT

General

Two types of vibrators are common on building sites – immersion vibrators and surface vibrators. Each has its own specific application, although on floors and other flatwork it is not uncommon for one to complement the other. A third type, form vibrators, are commonly used in precast work, and sometimes on building sites.

Immersion Vibrators

Frequently referred to as 'poker' or 'needle ' vibrators, immersion vibrators consist essentially of a tubular housing which contains a rotating eccentric weight. The out-of-balance rotating weight causes the casing to vibrate and, when immersed in concrete, the concrete itself. Depending on the diameter of the casing or head, and on the frequency and the amplitude of the vibration, an immersion vibrator may have a radius of action between 100 and 600 mm **Table 1**.

Immersion vibrators may be driven by:

- a flexible shaft connected to a petrol, diesel, or electric motor;
- an electric motor situated within the tubular casing;
- compressed air.

The effectiveness of an immersion vibrator is dependent on its frequency and amplitude, the latter being dependent on the size of the head, the eccentric moment and the head weight – the larger the head, the larger the amplitude.

Table 1 summarises the characteristics and applications of immersion vibrators. As a general rule, the radius of action of a given vibrator not only increases with the workability of the concrete (higher slump), but also with the diameter of the head. A good general rule is to use as large a diameter head as practicable, bearing in mind that vibrators with diameters in excess of 100 mm will probably require two men to handle them. Below this diameter, the appropriate head size will be dependent on the width of the formwork, the spacing of the reinforcement and the cover to it.

Immersion vibrators should be inserted vertically into concrete, as quickly as possible, and then held stationary until air bubbles cease to rise to the surface, usually in about 15–20 seconds **Figure 3**. The vibrator should then be slowly withdrawn and reinserted vertically in a fresh position adjacent to the first. These movements should be repeated in a regular pattern until all the concrete has been compacted **Figure 4**. Random insertions are likely to leave areas of the concrete uncompacted. The vibrator should not be used to cause concrete to flow horizontally in the forms, as

TABLE 1 Characteristics and applications of immersion vibrators

Diameter of head (mm)	**Recommended frequency**[1] (Hz)	**Average amplitude**[2] (mm)	**Radius of action**[3,5] (mm)	**Rate of concrete placement**[4,5] (m^3/h per vibrator)	**Application**
20–40	150–250	0.4–0.8	75–150	1–4	High slump concrete in very thin members and confined places. May be used to supplement larger vibrators where reinforcement or ducts cause congestion in forms.
30–65	140–210	0.5–1.0	125–250	2–8	Concrete of 100–150 mm slump in thin walls, columns, beams, precast piles, thin slabs, and along construction joints. May be used to supplement larger vibrators in confined areas.
50–90	130–200	0.6–1.3	175–350	6–20	Concrete (less than 80 mm slump) in normal construction, eg walls, floors, beams and columns in buildings.
75–150	120–180	0.8–1.5	300–500	11–31	Mass and structural concrete of 0 to 50 mm slump deposited in quantities up to $3m^3$ in relatively open forms of heavy construction.
125–175	90–140	1.0–2.0	400–600	19–38	Mass concrete in gravity dams, large piers, massive walls, etc.

Adapted from Table 5.1 ACI Committee Report: Guide for Consolidation of Concrete 309R-05 ACI Manual of Concrete Practice 2006 Part 2.

1 *While vibrator is operating in concrete.*

2 *Computed or measured. This is peak amplitude (half the peak-to-peak value), operating in air. Reduced by 15–20% when operating in concrete.*

3 *Distance over which concrete is fully consolidated.*

4 *Assumes insertion spacing 1½ times the radius of action, and that vibrator operates two-thirds of time concrete is being placed.*

5 *Reflects not only the capability of the vibrator but also differences in workability of the mix, degree of de-aeration desired, and other conditions experienced in construction.*

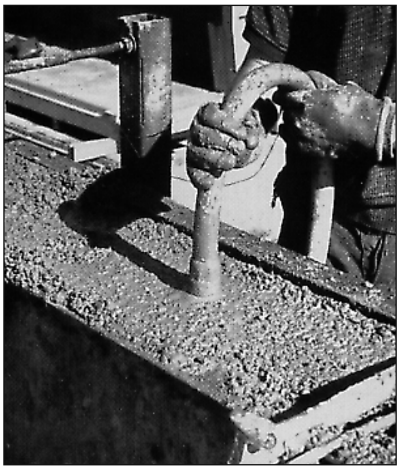

Figure 3: Use of an immersion vibrator

this can lead to segregation. In addition, the vibrator should not be dragged through the concrete as this leads to inadequate compaction and increases the risk of segregation.

In deep sections such as walls, footings and large columns, the concrete should be placed in layers about 300 mm thick. The vibrator should penetrate about 150 mm into the previous layer of fresh concrete to meld the two layers together and avoid 'cold-pour' lines on the finished surface. In small columns where concreting is continuous, the vibrator may be slowly raised as the concrete is placed. Care should be taken to avoid trapping air at the form face and a means of lighting the interior of the form while the concrete is being placed and vibrated should be considered.

The vibrator should not be allowed to touch the forms as this can cause 'burn' marks which will be reflected on the finished surface. Generally, the vibrator should be kept about 50 mm clear of the form face. Similarly, the vibrator should not be held against the reinforcement as this may cause its displacement.

Stop-ends, joints and, especially, inclined forms are prone to trapping air. To minimise this tendency, the best technique is to place the concrete close to, but away from the side of the form and insert the immersion vibrator close to the leading edge of the concrete, forcing it to properly fill the corner **Figure 5**.

Void-formers are also prone to trapping air on their undersides if concrete is placed from both sides and then compacted. Concrete should be placed at one side and, maintaining a head, vibrated until it appears at the other side. (Note that the void-former will need to be fixed so as to resist the pressure of the plastic concrete.)

When the top of the concrete is fully visible from above, then placing can continue normally **Figure 6**. This technique is used in other similar situations, such as encasing steel beams.

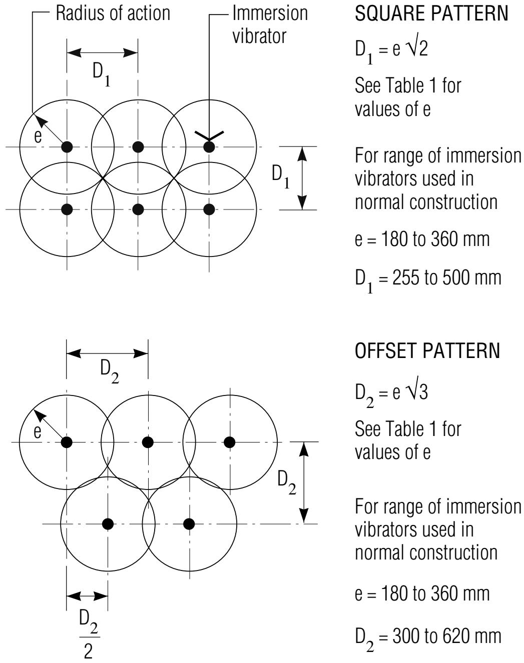

Figure 4: Alternative patterns for use of immersion vibrators

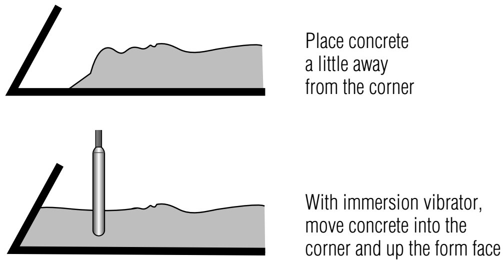

Figure 5: Compaction at stop ends and in inclined forms

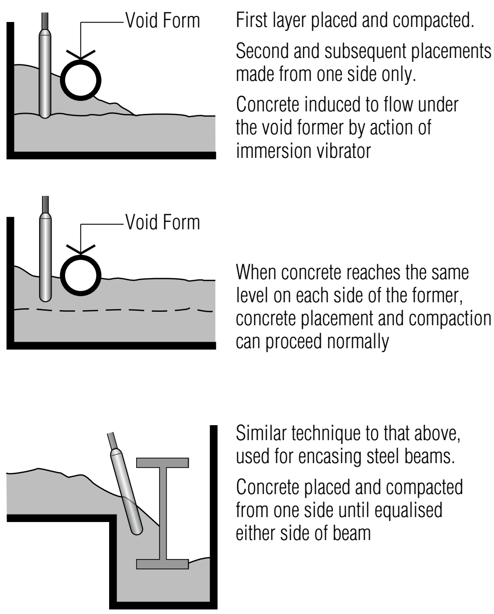

Figure 6: Compaction around void formers and encased members

Figure 7: Typical surface vibrator

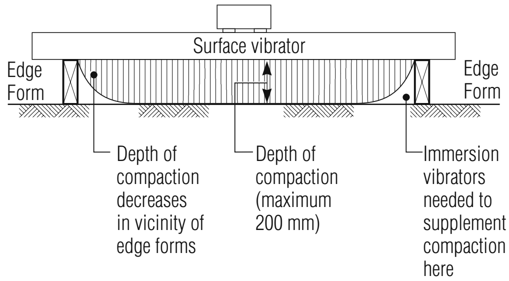

Figure 8: Degree of compaction varies across width when surface vibrators are used

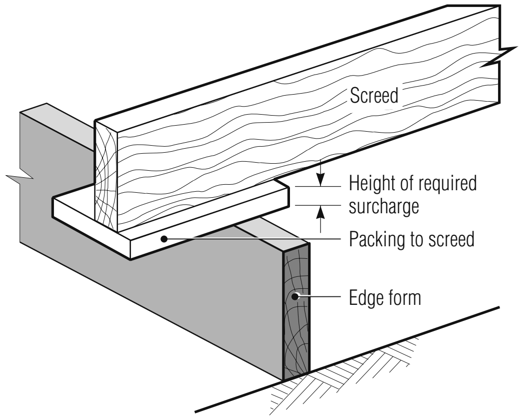

Figure 9: Method for providing a surchage to the uncompacted concrete

Surface Vibrators

Surface vibrators are applied to the top surface of concrete and act downwards from there. They are very useful for compacting slabs, industrial floors, road pavements, and similar flat surfaces. They also aid in levelling and finishing the surface.

There are a number of types of surface vibrators including vibrating-roller screeds, vibrating-beam screeds and pan-type vibrators which are used mainly on very specialised equipment such as road paving plant. The most common type is the single or double vibrating-beam screed.

A vibrating-beam screed consists of either one or two beams, made from aluminium, steel or timber, to which is attached a form of vibrating unit to allow the beams to impart adequate vibration to the concrete. This may be a single unit, mounted centrally, or may consist of a series of eccentric weights on a shaft driven from a motor on one end and supported on a trussed frame. In general, the centrally-mounted units have a maximum span of about 6 m, but the trussed units may span up to 20 m. The small units are normally pulled forward by hand whereas the larger units may be winched, towed or be self-propelled **Figure 7**.

The intensity of vibration, and hence the amount of compaction achieved, decreases with depth because surface vibrators act from the top down. Therefore, the slab thickness for which compaction by surface vibrators is effective will vary (from 100 to 200 mm) depending on the size and operation of the unit used. With slabs 200 mm or over in thickness, immersion vibrators should be used to supplement the surface vibrations

With centrally-mounted vibration units, the degree of compaction achieved may vary across the width of the beam. When they rest on edge forms, the latter may tend to damp the vibration at the extremities of the beam **Figure 8**. It is generally desirable, therefore, to supplement vibrating-beam compaction by using immersion vibrators alongside edge forms.

The effectiveness of vibration, and hence degree of compaction, increases with an increase in the beam weight, the amplitude and the frequency, and decreases with an increase in forward speed. Forward speed is critical in the correct use of vibrating-beam screeds and should be limited to between 0.5 and 1.0 m/min. The lower speed should be used for thicker slabs and where reinforcement is close to the top face. A second, faster pass may be made as an aid to finishing.

In using vibrating-beam screeds to compact concrete, the uncompacted concrete should first be roughly levelled to above the final level required, ie a surcharge should be provided to compensate for the reduction in slab thickness caused by the compaction of the concrete. The amount of surcharge should be such that, when the beam is moved forward, a consistent 'roll' of concrete is maintained ahead of the beam. The surcharge may be provided evenly on slabs of up to 4 m in width by the use of a 'surcharge-beam'. This is simply a straightedge, usually made of timber, with small packing pieces on the ends which 'ride' on the edge forms **Figure 9**.

The surcharge beam is pulled over the uncompacted concrete without any attempt being made to compact or finish it. The sole purpose is to provide an even surcharge. The correct thickness for the packing pieces (and hence the surcharge) is soon found by observing the 'roll' of concrete. Providing an even surcharge has the advantage that one pass of the vibrating-beam screed is generally sufficient to compact, level and provide the initial finish. This is preferable to multiple passes, as a slower single pass is more effective in compacting the concrete than two faster passes.

Form Vibrators

Form vibrators (normally called 'external' vibrators) are useful with complicated members or where the reinforcement is highly congested. They are clamped to the outside of the formwork and vibrate it, thus compacting the concrete. The formwork will need to be specifically designed to resist the forces imposed on it.

Under-Vibration and Over-Vibration

Normal-weight concretes that are well proportioned are not readily susceptible to defects caused by over-vibration. These result from segregation and are characterised by an excessive thickness of mortar at the surface of the concrete. The surface may also have a frothy appearance. Over-vibration may cause problems when grossly oversized equipment is operated for an excessive length of time, but is more likely to cause problems with poorly-proportioned mixes or those to which excessive amounts of water have been added.

When signs of over-vibration are detected, the initial reaction may be to reduce the amount of vibration. The most appropriate solution may be to investigate if suitable changes to mix design are warranted.

Under-vibration is far more common than over-vibration and, when it occurs, can cause serious defects. Invariably, the concrete is incompletely compacted which reduces its strength (see *Effect on Hardened Properties* above), its durability and will possibly affect its surface finish.

Despite this, many specifications contain a caution against the over-vibration – and even lay down a maximum length of time for vibration – whilst neglecting totally the question of under-vibration.

Revibration

Revibration of concrete is the intentional systematic vibration of concrete which has been compacted some time earlier. It should not be confused with the double vibration which sometimes occurs with the haphazard use of immersion vibrators or multiple passes of a vibrating-beam screed.

Whilst it is generally agreed that revibration of concrete can be beneficial to its strength, its bond to reinforcement and its surface finish, the practice is not widely used, partly due to the difficulty of knowing just how late it can be applied. A good rule of thumb is that revibration may be used as long as the vibrator is capable of liquefying the concrete and sinking into it under its own weight.

Situations in which revibration may be beneficial include:

- To bond layers of concrete into those preceding them. In elements such as walls, deep beams and columns, which are being filled in successive layers, the vibrator should just penetrate the previous layer.
- To close plastic shrinkage and settlement cracks.
  These may form within the first few hours of concrete being placed and may be able to be closed by vibration, providing it is done early and prior to the hardening of the concrete. However, a reasonable level of energy input is required since mere reworking of the surface, may simply close the cracks superficially. They may then reopen as the concrete dries out.
- To improve the surface finish at the tops of columns and walls by expelling the air which tends to congregate there as the concrete settles in the formwork.
- To improve the wear resistance of floors. Revibration, coupled with a trowelling action, helps to create a burnished wear-resistant surface layer.

FURTHER INFORMATION

Further information on good concreting practices can be downloaded from the Cement Concrete & Aggregates Australia website at **www.concrete.net.au**.

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