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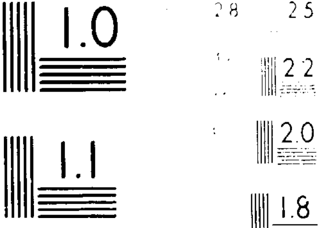

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GENERAL INTRODUCTION TO PRECAST CONCRETE MANUFACTURING TECHNIQUES *

by
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CONTENTS

1. INTRODUCTION

Prefabrication of concrete components for the building and construction industry is a firmly established technique in Australia. Although prefabrication is possible adjacent to a building site, it is generally more effective in a factory remote from the site. This in turn has allowed development of refined manufacturing techniques and an accordingly higher degree of specialisation.

The art of designing and constructing with concrete as a building material is the art of selecting combinations of materials and procedures which are compatible, offer the required structural resistance to loads, remain serviceable and aethetically pleasing for the life of the structure.

To achieve this end, one must take account of the inherent limitations of materials being used, pay close attention to detail and supervision during manufacture.

2. PRODUCTION IS CYCLIC DAILY

To remain economically viable, all production should relate to a 24-hour cycle or less. This means a concrete product is manufactured from a mould every day.

A typical working day could be broken down as follows: -

6 A.M.	Completion of previous day curing.
7 A.M.	Remove product from mould and complete finishing operations.
8 A.M.	Clean and re-lubricate mould.
9 A.M.	Place anchors, fitments and reinforcing cage into position.
11 A.M.	Locate sides and close mould ready for concreting
1 P.M.	Pour concrete and finish, then cover.
3 P.M.	Allow preset approximately 3-4 hours for initial maturity to develop.
7 P.M.	Begin accelerated curing cycle.
5 A.M.	Shut boiler down.
6 A.M.	Completion of previous day curing.

3. MOULDS

Product quality is to a high degree reflected by quality of the moulds from which the units are cast. Design differs slightly from approaches on conventional building work. In addition to satisfying requirements for strength and deflection under hydrostatic load of wet concrete, most moulds are designed to witnstand high frequency vibration from externally attached vibrators, rigidity to withstand the number of times a mould is dismantled which could be up to approximately 200 times, abuse and misuse, and the corrosive environment in the steam curing atmosphere.

Elements of good mould design include: -

- Accuracy in construction to achieve required tolerances including positioning of ancillary hardware.
- Easily dismantled without causing damage to delicate sections such as fins and rebates.
- Provision for uniform and efficient finishing of units.
- Standardisation of positions for cast-in hardware.
- Mast mould concept. Variations to profile are catered for by extensions, deletions, blockouts etc. within a complex mould.
- Access under mould for free circulation of steam.
- Provision to attach external vibrators.
- High mass and rigidity in side plate bracing for efficient dispersion of vibration energy to consolidate concrete.
- Design of joint details which are grout tight to prevent leaking of bleed water and subsequent discolouration.
- Provide adequate tapers for easy removal of cores and the like to prevent jamming and damage to product.

Adequate rigidity in bracing system to prevent "pumping" of mould during compaction. Failure to design for this aspect could result in "aggregate transparency" resulting in a "mottled" off form surface.

Fibreglass linings have been used for mould profiles, generally in highly sculptured work or when other materials would provide awkward solutions.

Combinations of timber boards or marine plywood linings together with steel frame and bracings may also provide economical solutions.

4. MATERIALS

To ensure long term durability, even surface finishes and optimum weathering characteristics, the selection of raw materials plays an important role.

4.1. Cement

The main cement types used in precast are white, off white, grey type I portland cement.

Cement of the same type and brand and from the same mill should be used for units on a given project to minimise colour variations. This is particularly important with off form finishes.

When particularly high strengths are required at an early age, look for a cement with high C_3S, high fineness and low C_3A content.

4.2. Aggregates

Frequently combinations of different aggregate types and grading are used for architectural effect. Such aggregate includes river gravels, quartz, marble, basalt, granite, diorite and others.

Aggregates are normally gap grades into about three fractions from 20mm to dust. This allows for more uniform surface finish as stones are uniformly proportioned, reduces the risk of concrete segregation and helps to control colour variation from unit to unit as the stone dust fraction serves to replace the normal fine aggregate.

Occasionally, facing aggregates may contain particles with an iron content or petrified wood which could result in unsightly staining. Selectivity on the part of the precaster and his experience with materials and sources are currently the only safeguard against iron stains from aggregate.

Laboratory tests should be performed - particle shape, abrasion if required, absorption, alkali reaction, soundness and performance in an acid environment.

4.3. Admixtures

Water reducing and set retarding admixtures are sometimes used mostly of the liguosulphonate type. Superplasticisers are finding wide application in that they allow the use of highly workable concrete whilst retaining the properties of concrete normally only obtainable with extremely stiff and difficult to place concrete.

Admixtures containing $CaCl_2$, should not be used.

Air entraining agents are beneficial in reducing bleeding in concrete, an aid to increased workability and resistance to freeze/thaw conditions.

Inhibitors should be added to wet concrete if galvanised reinforcement is being used. Common agents include Potassium dichromate and chronium trioxide in proportion of 300ppm of mixing water.

If pigments or colouring agents are used, they should have an inorganic base such as oxides of metals. They should be resistant to lime and other alkalis. Manufacturers tests are advisable.

4.4. Water

Water should be chemically checked if not suitable for human consumption. Three important tests include sugar, chloride ion and sulphates.

4.5. Reinforcement

Precast concrete sections should be designed on properties of the gross concrete section uncracked in flexure or alternatively on a limited steel stress around 120 mpa if sections are allowed to undergo controlled cracking. Accordingly, there should not be a need to use C grade steel.

Important aspects to consider include: -

- Avoid the use of high carbon grade steel
- Use structural grade or ordinary grade to allow easy bending and welding.
- Limit stress levels to account for likely effect of cracking
- Use fabric where possible. It is easier to place and labour costs are reduced.
- Use a larger number of smaller bars instead of a few large bars distributed evenly across the tensile zones
- Galvanised reinforcement should not be necessary. If sections become less than 75mm thick and are exposed to environment, consideration should be given to galvanising. It is likely to increase cost of reinforcement by 50%. Inhibitors are required and dissimilar metals should be isolated.
- Generally beneficial to draw congested reinforcement details full size prior to formulating bending schedules. This will highlight problem areas of tight bends, insufficient concrete cover and clashes with laps, etc.

4.6. Concrete

Reinforcement embedded in concrete is protected from corrosion by the high alkalinity afforded by cement reactions, (around pH=11). Subsequent carbonation of outer layers by carbon dioxide dissolved in the atmosphere reduces calcium hydroxide (ph $\approx$ 12) to calcium carbonate (pH $\approx$ 7) which offers no protection to reinforcement. Consequently concrete should have the following characteristics to remain durable for many years: -

- High cement content (around 360-380 kg/m^3)
- Water/cement approximately 0.4 to 0.48 ,
- Adequately and densely compacted by mechnical means.
- Sufficient curing and development of maturity prior to loading.
- Adequate clear concrete cover to reinforcement particularly in awkward locations and longitudinal reinforcement.

5. MIX DESIGN

Since precasting involves stripping unit at early ages, rapid strength development is important. Consequently, although 28-day strengths are usually specified, they rarely control mix designs in a precast factory.

It is customary to use gap graded mixes as they result in a denser concentration of particle at the mould surface for a particular finish. Gap graded mixes are essential for creating exposed washed aggregate, bush hammered and polished surfaces.

Other consequences arising from a gap graded mix include: -

- Higher potential strength than a continuously graded mix
- Less tendency to settle after compaction
- Sensitive to water content. It is obvious if too much water is present and therefore serves as a gross quality control perimeter
- Liquifies, but does not segregate under vibration in the slump range from 30 to 60 mm. Typical mix proportions for large stone concentrations are as follows: -

Cement	=	1
Coarse Aggregate	=	3
Fine Aggregate	=	1

$\frac{\text{Aggregate}}{\text{Cement}}$ varies from 4 to 7

$\frac{\text{Water}}{\text{Cement}}$ varies between 0.4 to 0.48

6. STEAM CURING

Factory produced precast concrete depends for its economy on a daily turn-around of moulds. This can be achieved if a relatively high compressive strength (about 25-30 MPa) is obtained approximately 18 hours after mixing the last concrete for a product. There are thus two prerequisites for a successful factory operation.

- Concrete made with high quality cement and aggregates, good quality control.
- Curing cycles to ensure the required strength is obtained at early ages.

Curing is achieved with the aid of low pressure steam injected under covers which contain the products to be cured. The heating of a body by means of steam depends on the principle that the steam condenses on the cooler body and gives up latent heat to it. Steam at low pressure has more latent heat per kg than steam at high pressure, thus for heating purposes, it is more efficient to use steam at the lowest possible pressure.

Since an increase in the curing temperature of concrete increases its rate of development of strength, the process can be speeded up by curing concrete in steam. When steam is at atmospheric pressure i.e. the temperature is below $100^{\circ}C$, process may be regarded as a special case of moist curing.

The important aspects of a steam cycle are: -

- Initial "maturity" should be greater than 40° c.hr before steam is applied. This is sometimes referred to as a "preset" period and for Sydney climate requires between 3 to 5 hours before application of steam.

  Maturity is the product of time (hours) and temperature ($^{\circ}C$).

- Rate of temperature rise should be limited to 24° C/hr and not greater than 6° C per any 15 minute period.
- Maximum temperature should be limited to 80-85° C and 75° C for lightweight concrete.

A recommended steam curing cycle is shown in figure 6.1.

Steam curing will be optimised if applied in accordance with the graph shown and the more nearly the curing cycle approaches the limits of the graphs, the higher will be the strength of concrete at early ages.

If the delay period is not observed before applying steam, a decrease in strength results probably through micro-cracking of the concrete caused by its expansion during the setting process. If the rise exceeds 25° C/hr, micro-cracking is likely. Excessive rapid heating can cause a later loss of strength by as much as one third compared with water cured concrete. See Zone B of figure 6.2.

Concrete cured to the recommended cycle exhibits 5-10% lower strength at 28 days compared to water cured concrete. Zone A of figure 6.2 applies.

A typical thermograph which has recorded the chamber temperature of the curing atmosphere is shown in figure 6.3.

The ideal cycle of figure 6.1 is not always desirable for panel manufacture because very high strengths are not required and thus there is a saving in fuel costs.

Low steam cycles are particularly important for retarted exposed concrete panel manufacture. Generally, the expertise of the precaster determines a particular cycle somewhere between the extremes indicated. The only real variation is the maximum temperature reached and the duration of maximum temperature.

7. STEEL MOULDS AND STEAM CURING

Although the coefficient of expansion of steel and hardened concrete are somewhat similar, the thermal conductivities and specific heats of steel and fresh concrete are not and before putting any steam curing process into operation, an attempt must be made to anticipate any problems which might be caused by differential expansion of the mould and the concrete.

When a steel mould is filled with fresh concrete and suddenly surrounded by steam at high temperature, it will expand and the mass of concrete immediately tends to accommodate its shape to that of the mould. If some delay is introduced by virtue of a preset period, the concrete has begun to harden before being passed into the curing chamber.

It does not expand as quickly as the mould, and if the shape of the unit interlocks in any way with the mould (e.g. through shear keys) tension is induced and the concrete may crack. Similarly, if a unit is not demoulded quickly when removed from a hot curing chamber, the rapid contraction of the mould may induce destructive compressive stresses in certain parts of the unit.

Once the units have been demoulded, there appears to be no problem with rapid cooling unless differential heat losses become great as is sometimes the case with tee beams having thick webs and thin flanges.

It will sometimes be necessary to incorporate expansion joints or compressible material into those areas of a mould which would cause cracking of the concrete during the contraction or expansion stage (e.g. square ended returns to both ends of long units).

8. VENEER FACED PANELS

Veneer construction in precast concrete is the term used to describe a precast unit having a thin layer of decorative surface concrete applied over a grey structural concrete backing. The veneer material is normally applied the same day as the backing concrete is cast and usually within the first couple of hours after casting. Veneer construction is usually only used where the materials required on the exposed surface of the panel are too expensive to use throughout the body of the panel. e.g. white cement or special aggregates. The aggregate in veneer concrete may be subsequently exposed by water washing, sand blasting or other techniques.

An important parameter of concrete strength is bond between aggregates and cement paste. It should be much simpler to achieve adequate bond between two surfaces both of which have cementing properties such as in veneer construction than between cement paste and aggregate. Only a low quality concrete surface, inclusion of dirt or other material on the surface are likely to affect the bond between the backing and veneer concretes.

The "Precast Concrete Recommended Practice" require that: -

> "Proper care shall be taken to remove any laitance from the surface of the initial layer against which the subsequent layer of concrete is to be cast to ensure that adequate bond can be developed. If more than 20 minutes elapses between casting the first and second layers of concrete, the surface of the first layer shall be raked or otherwise mechanically roughened before the time of initial set. Where the second layer is cast after the initial set of the first layer has taken place, vibration of the second layer shall be such as not to disturb the first layer.
>
> If bleed water is present on the surface of the first layer, placement of second layer should be delayed until all bleed water has either evaportated or re-absorbed into the concrete. The surface of the first layer should then be roughened as it will certainly be covered by a laitance skin.
>
> Shrinkage differentials will always exist between the two concretes being placed and can be responsible for bond failure where adequate bond has not been established at the time of manufacture. Where good bond exists between the layers the veneer will normally crack into a pattern of very fine cracks at close centres. This will permit differential movement between the two

layers and thus avoid curling and recurring high shear stress at the interface.

If good bond has not been achieved, any tendency to shrink or curl may well result in partial or complete bond failure.

As bleeding of concrete is a physical function and setting a chemical function, retardation of the mix with more than normal bleeding potential could assist in obtaining good bond particularly in hot weather. The use of retarders or other admixtures should not be used indiscriminately."

In summary, the following should be noted: -

- Ensure adequate bond between the two surfaces.
- Bleed water must not be present at the interface.
- Laitance at interface must be removed.
- Roughen surface if casting is delayed for short intervals.
- Caution with vibration if initial set has taken place.
- Do not use cement or chemical driers.
- Consider set retarding admixtures in hot climates.
- Design mixes to minimise shrinkage differentials.
- Use compatible materials.
- Practical minimum thickness of veneer about 25mm.
- Small and delicate areas may be solid veneer.
- Avoid excessive time delays.

9. PLACEMENTS AND COMPACTION OF CONCRETE

A) Flat Surfaces

Units may be cast either face up or face down. To obtain an even finish where panels are poured finished face down (in contact with mould surface) the entire mould surface should be covered with concrete before compaction begins. When veneers are being placed, it must be spread evenly with hand tools or screed bar to prevent poor lines between adjacent batches of concrete from developing.

The defect normally shows as bonds of matrix devoid of aggregate. Vibration should be of short duration but intense which makes high frequency vibration ideally suitable. High frequency compaction equipment operates between 9 - 12,000Hz whereby excitation amplitudes are generated by rotating eccentr... ..lly mounted discs. This method of compaction excit..s t... whole concrete mass whereby the paste becomes more viscous with increasing frequency so that liquifaction of the concrete takes place to allow uniform surface density of aggregate in matrix.

Attention should be paid to vibrator orientation. They should be set and located that rotation of discs takes place in opposite directions across the mould. This maximises compaction effectiveness and also prevents the tendency of concrete to "walk" across the mould surface.

After compaction of the veneer concrete is complete, reinforcement is positioned and then the backing concrete layed. Care must be taken to ensure complete bond at the interface but vibration time short enough to prevent grey matrix of backing concrete to penetrate the finished surface.

Where the finished surface is uppermost, the same guidelines apply. For uniformity, the surface should be tamped with a roller which is wider than the mould and rests on the mould sides. Trowel marks and slurry lines will be eliminated. Barely noticeable deviations in a surface during manufacture can show vividly in oblique lighting conditions.

B) Vertical Surfaces

Require considerably more care to achieve a consistent finish. To pour U shape sections, the difficulty is in maintaining uniformity between horizontal and vertical face. A consistent technique is essential. The mould is filled from one leg only with concrete travelling across horizontal section of the U and the vertical leg filled by lift due to out of balance pressures. This technique ensures maximum exclusion of entrapped air and eliminates slurry lines where batches of concrete meet.

For best results, mix should have a slump range 100-120mm and remain cohesive during compaction. A constant danger of segregation exists if concrete is over vibrated.

Long members are most conveniently cast from one end. Concrete tends to flow along the member with a long toe at the front. Consecutive batches are placed toward the top of the toe, thus eliminating pour lines and minimise inclusion of entrapped air. Arching of concrete at constrictions and hole formers or ducts is less likely than if mould is filled in layers from the bottom up.

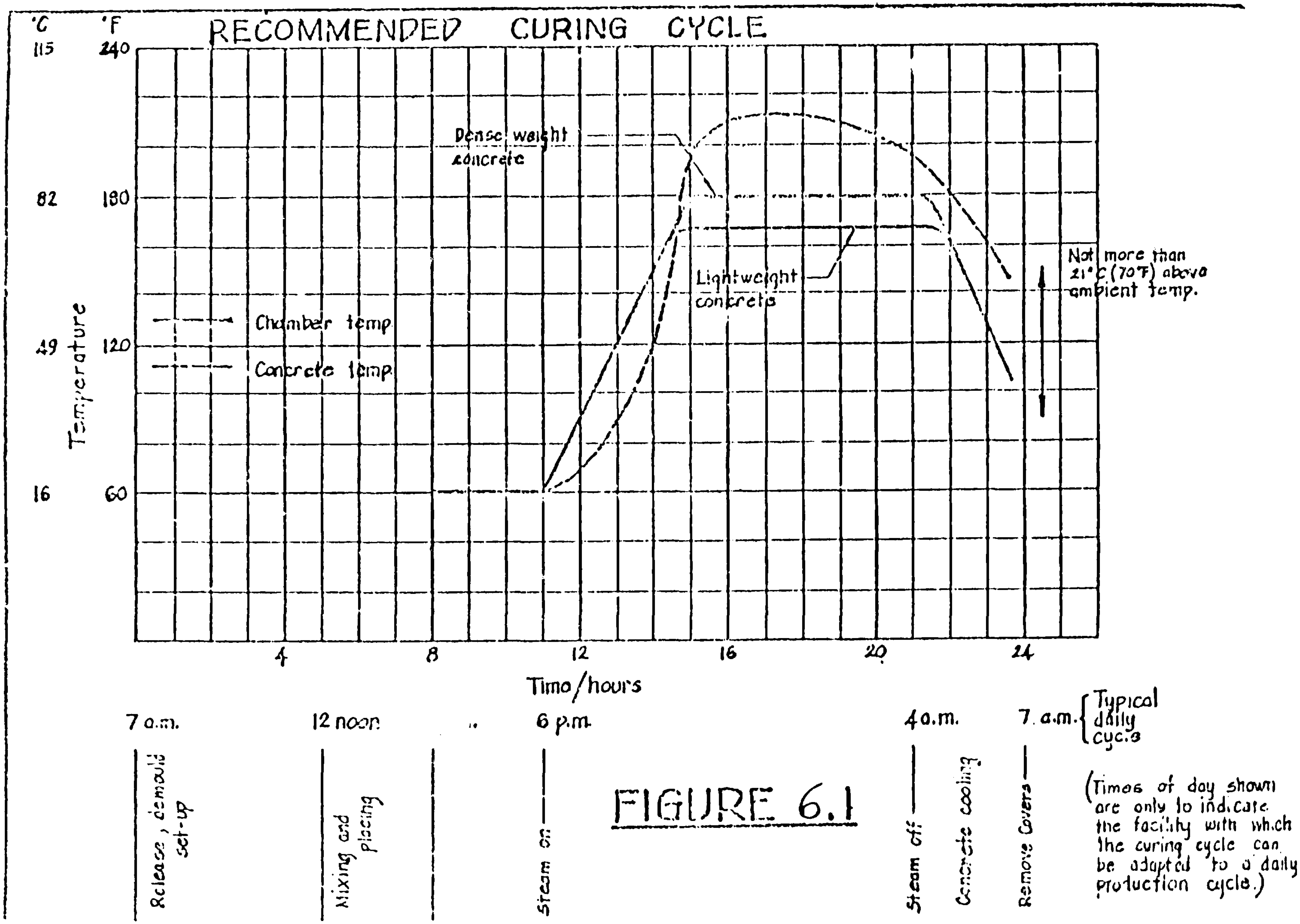
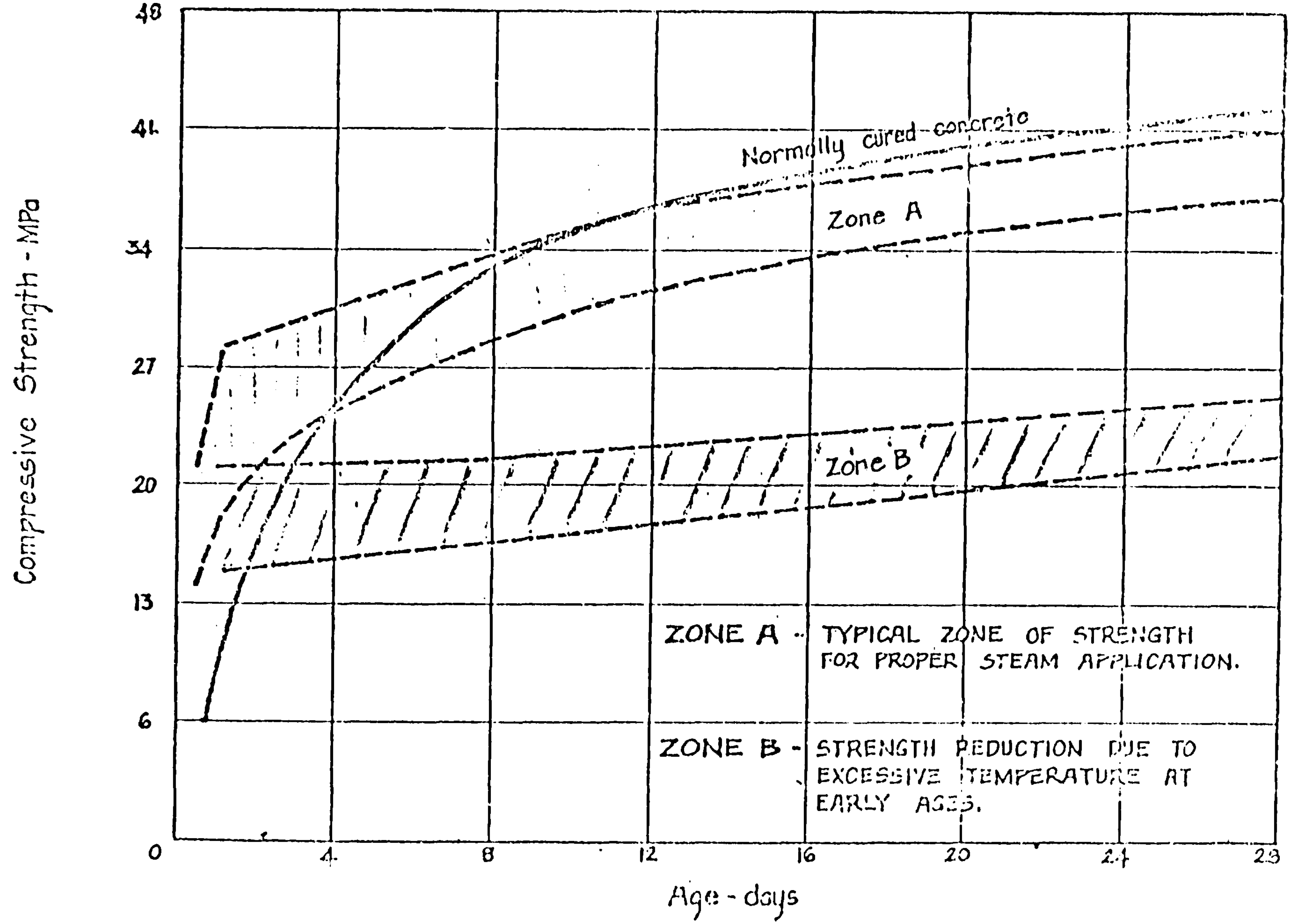

RECOMMENDED CURING CYCLE
°C
°F
115
240
82
180
49
120
16
60
Temperature
Dense weight concrete
Lightweight concrete
Chamber temp.
Concrete temp.
Not more than 21°C (70°F) above ambient temp.
4
8
12
16
20
24
Time/hours
7 a.m.
12 noon
6 p.m.
4 a.m.
7 a.m.
Typical daily cycle
Release, demould set-up
Mixing and placing
Steam on
Steam off
Concrete cooling
Remove Covers
(Times of day shown are only to indicate the facility with which the curing cycle can be adapted to a daily production cycle.)

FIGURE 6.1

FIGURE 6.2



Compressive Strength - MPa
48
41
34
27
20
13
6
0
4
8
12
16
20
24
28
Age - days
Normally cured concrete
Zone A
Zone B
ZONE A - TYPICAL ZONE OF STRENGTH FOR PROPER STEAM APPLICATION.
ZONE B - STRENGTH REDUCTION DUE TO EXCESSIVE TEMPERATURE AT EARLY AGES.

FIGURE 63