(3) Improved watertight character of the concrete, to prevent the ingress of water containing injurious concentrations of sulphate and chloride ions;

(4) An accelerated rate of strength gain in mixes using Type V (sulphate resisting) cements;

(5) A retarded rate of initial set and fall off of workability;

(6) A reduced rate of heat release, which occurs due to accelerated hydration;

(7) Reinstatement of the initially achieved workability.

IV:(a) High Range Water Reduction and Reduction of Cement Conte

The high water reduction required for mixes commonly used in the Middle East (viz. high cement contents and low water cement ratios) entails the use of high dosages of conventional admixtures. Consequently, the reports of attendant adverse side effects (severe bleeding, retardation, heavy air entrainment are quite common in many construction sites. In such situations the use of superplasticizers, which provide the requisite plasticity and water reduction (20-25%) without damaging side effects, is a boon to the Concrete Engineer and Production Superintendent. Frequently specified water:cement ratios of less than 0.5 are readily met with superplasticizers at dosages of 2-2.5% (by weight of cement) for the 20% solids solution of melamine-formaldehyde type and 1.2 - 1.8% for the 40% solids solution of the naphthalene-formaldehyde type superplasticizers. The engineer is, therefore, assured of achieving favourable strength margins and hence reasonable economy in mix design. Table III shows the water reducing capability of a naphthalene-formaldehyde based superplasticizer

at two fixed workabilities.

The water reducing aspect of superplasticizers is seen in the construction of stabbits for a harbour breakwater project in Saudi Arabia. Sulphate resisting cement was specified for the 350 kg/m^3 cement content mix. The coarse aggregate (20 mm) was highly angular and of poor texture while the sand was a beach sand of F.M. 1.6. The maximum permitted water:cement ratio was 0.52 and the placing slump of 100 mm was expected to flow and fill the 4.2 m^3 mould with minimal vibration. The contractors desire to obtain favourable production cycles called for strength acceleration at early ages.

Several conventional lignosulphonate based water reducers were tried at high dosages. However, the high ambient temperatures (40°C) and water demand by the fine sand made it impossible to attain the 0.52 water:cement ratio without severe bleeding and segregation, occuring in the mix.

The contractor in an attempt to offset the mounting costs of retaining hundreds of idle workmen agreed to try a superplasticizer - despite the high cost he would incur. A melamine formaldehyde based superplasticizer was used at a 2.5% dosage with the mix adjusted with a decreased fines content. A 20% water reduction (over plain mix) was achieved to provide a mix with the required water:cement ratio, plus adequate cohesion and workability at a 75 mm slump. Reasonable stripping strengths of 11 N/mm^2 were achieved, enabling the contractor to cope with the required production schedules.

The construction of large caissons for use in jetties involves the placing of large pours of concrete mixes with high cement contents (> 375 kg/m^3). The high core temperatures that build up are maintained for long periods due to the poor dissipation of heat to the hot surroundings. Consequently there is a great risk of thermal cracking occurring when the units are demoulded even after 72 hours. La Fraugh(1) has reported 11-20% cement reduction through use of superplasticizers in mixes of 415 kg/m^3 cement content while maintaining desired strength levels. The permissible cement reduction could well be used in these situations to reduce the core temperature and hence the potential cracking.

IV:(b) Sulphate attack and Alkali Aggregate Reaction

The complex variety of salts that exist in the Middle East pose problems of both internal and external attack on the concrete. External attack occurs by 2 principal means, typical sulphate attack by ingress of water containing chloride and sulphate ions, and salt weathering and salt crystalization. The latter is the result of salts crystallizing out in the pores of the concrete matrix and the aggregate particles, thereby setting up expansive forces. Intrinsic attack is due to typical alkali aggregate reaction.

Middle East Aggregates that are chemically reactive fall into two broad groups: one dominated by reactive silica minerals, and the other by carbonates. However, the amount of reactive ingredient necessary to cause damage is often so small that nearly all rock types may be considered suspect: all

the reactions involve alkali metal ions (Sodium & Potassium) together with other components of the aggregate and cement. Although the alkalies derive mainly from the cement, the salts contaminating the aggregates often make a major contribution to the total alkali present in the concrete.

The reason for expansion - cracking associated with alkali-aggregate reaction is not yet fully understood. However, on the basis of published literature(2) four main theories have been identified: (a) swelling of alkali-sensitive aggregate under the action of alkali-hydroxide solution, (b) volumetric increase associated with the transformation of the original particle to alkali-silicate hydrate, (c) swelling of the alkali-silicate gel when water has access to it and (d) development of osmotic pressure in the alkali-silicate solution.

The mechanisms outlined above, show the importance of the presence of intrinsic water and other related properties like porosity and permeability to concrete durability. It is, therefore, evident that the permissible water reductions (up to 30%) obtained through the use of superplasticizers play a significant role in reducing the extent of deterioration of concrete that results from the presence of intrinsic sulphate and chlorides or other reactive components in the aggregate. The lower water contents in mixes no doubt reduces the amount of chloride, sulphate and alkali hydroxide solutions present in the hardened concrete. Thus disruptive expansion through chemical attack is reduced.

IV:(c) High Strength Impact Resistant Concrete

In certain situations such as roll on the roll off quays, the concrete is called upon to withstand severe impact and abrasion stresses arising from the off loading of heavy equipment and material. Concretes of compressive strengths 42 N/mm^2 subjected to such withering loads soon crack and fall apart. The class of concrete (strengths in excess of 55 N/mm^2 that meets these demands is under Middle East conditions, incumbent with the aforementioned problems. Even with well graded aggregates, high cement factors ($>$415 kg/m^3) and very low water:cement ratios ($<$ 0.36) are required to ensure consistent strength results. These measures, however, do not afford a workable concrete that is readily placed. The very high water reduction ($>$25%) and concurrent plasticity (50-75 mm slump) called for can only be supplied with an admixture which gives significant water reduction at high dosages without retardation. A melamine-formaldehyde based superplasticizer was used effectively in this type of application. A mix of 415 kg/m^3 cement contents, and 10 mm aggregate size, was used to pour 100 mm thick abrasion pads on the loading bays. The dense pads were proof tested and showed excellent capability of absorbing the shock impact stresses and also resistance to erosion by abrasive forces.

IV:(d) Early Strength Development in Mixes Using ASTM Type V Cements

Precast concrete operations throughout the Middle East are often faced with the problem of coping with poor production cycles due to the use of Type V Cements. In these situations

many of the larger precast plants resorted to the use of superplasticizers to obtain reasonable if not desired manufacturing schedules. The lower C_3A contents of Type V cements which enhance the water reduction obtained with superplasticizers promotes early strength development and the requisite stripping strengths. Table IV shows the early strength capability of water reduced concrete containing a melamine-formaldehyde superplasticizer.

In some plants superplasticizers have been used to reduce the period of heat curing of concrete. The substantial mix water reduction which contributes to large increases in early strengths has been used by a Kuwait Precast Producer of building panels to reduce his 16 - 18 hour heat curing cycle to 6 hours thereby significantly improving his turnover of forms. Other beneficial effects included the ease of compaction, trowelability and a decrease in shrinkage cracks.

IV:(e) Slump Loss

The high ambient temperature in the Middle East represents the most limiting condition in the use of superplasticizers. Many of these admixtures are susceptible to a rapid slump loss even at normal temperatures (22°C). At temperatures in excess of 22°C this trend is accellerated (Fig. II). Several techniques to overcome this problem have been suggested[3]. They are as follows:

(a) The production of an initial high slump, and allowing the natural slump loss to occur prior to discharge;

(b) Incremental addition of more admixture to restore the original slump;

(c) The use of a retarding superplasticizer;

(d) The addition of a hydroxycarboxylic (H.C.) type retarding admixture prior to the addition of a superplasticizer.

Method (a) is a counter-productive measure since it obviates the water reduction obtained through the use of a superplasticizer. The use of a retarding superplasticizer and repeated dosages are limited to specific uses or problem areas. Method (d) has flexibility in use and is a readily controllable means of reducing slump loss problems. Both Hester[4] and Mailvaganam[5] have reported the successful use of H.C. type retarders to offset the fall off of high workability. Two users of superplasticizers in the Kuwait area have incorporated the latter technique in their production cycle and effectively overcome previous slump loss problems.

Figs. (II) and (III) show the enhanced retention of the state of maximum workability obtained through the use of both H. C. type admixtures and retarding superplasticizers.

IV:(f) Re-dosage of Superplasticizers to re-instate Workability

Due to the distances involved in the transport of concrete before it is placed, handling time is extended and substantial mixing time cannot be avoided. Prolonged mixing, particularly at elevated concrete temperatures, induces loss of consistency. Consequently there are not infrequent cases in which retempering of the mix with additional water to provide the desired workability is carried out. The serious loss of strength that results from the addition of water warrants

concern. It is, therefore, fruitful to consider the use of superplasticizers for this purpose. The addition of another dose of the admixture and a short remixing at the job site before discharge will provide a slump that is readily placed.

In the work done by Ravina[6] and Previte[7] it was shown that both conventional and superplasticizing admixtures could be used to minimize the amount of water required for retempering so that loss of strength was minimized. (Table V). More recent work by Seabrook and Malhotra[8] and Mailvaganam[5] indicates that superplasticizers can be used effectively to re-instate the initial consistency without loss of strength. (Table VI & Figs. IV & V). It is not certain as to how many subsequent additions can be made before it becomes detrimental to the concrete. Laboratory investigations by Perenchio[9] et al and field experience by Hester (4) indicate that depending on the type of superplasticizer used, incremental dosages of the admixture may result in either mild acceleration or significant retardation. The performance of each superplasticizing admixture in this respect is thought to be governed by an inherent response of the admixture to a given type of cement. Seabrook and Malhotra[8] found that the magnitude of the effect produced by redosage is closely related to the water:cement ratio. Mixes with water:cement ratios less than 0.55 appear to respond favourably to redosage and attain initial high slumps with adequate mix cohesion. At slumps of 0.65 there appeared to be a more drastic and cumulative effect whereby re-dosing at the same initial level produced severe bleeding and segregation. Most reports indicate that at least