TABLE 5--ADMIXTURES USED

Kind	Mark	Main component
AE agent	AE	Alkyl-Allylsulfonate
AE water-reducing admixture	AEWR	Lignosulfonate acid
Superplasticizer	SP-1	Modified Lignosulfonate Melamine compound
	SP-2	Calcium Naphtalinesulfonate compound
	SP-3	Melaminesulfonate compound

TABLE 6--MIX PROPORTION OF CONCRETE

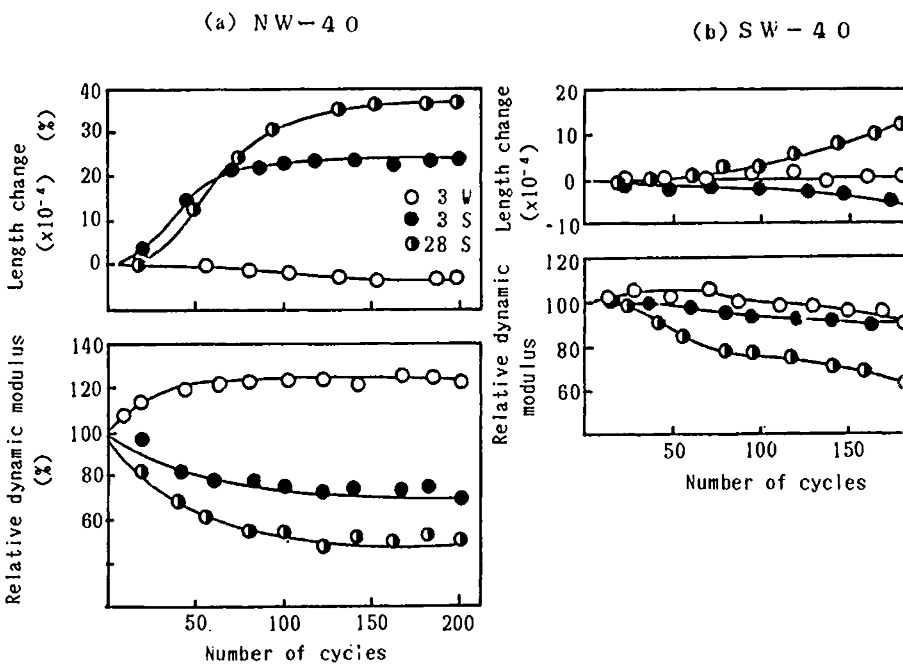
Admixture		W/C	s/a	Unit weight(kg/m³)		Slump	Air
Kind	Dosage	(%)	(%)	Water	Cement	(cm)	(%)
Nil	—	45.1	40	450	203	11.0	1.7
AE	C×0.009 %	41.6	38	450	187	12.5	4.3
AEWR	C×0.5 %	42.5	38	405	172	10.5	4.5
SP-1	C×1.2 %	39.6	38	405	159	17.0	4:8
AEWR + SP-2	C×0.5 % C×0.35%	39.6	38	405	159	14.5	4.2
AEWR + SP-3	C×0.5 % C×0.6 %	39.6	38	405	159	18.5	4.6

TABLE 7--MEASUREMENT OF RUST OCCURRENCE

Exposure spot	Class	Age (Years)	Covering depth : 20mm		Covering depth : 30mm		Covering depth : 60mm	
			The ratio of the area of average rust occurrence (%)	Rank of rust occurrence	The ratio of the area of average rust occurrence (%)	Rank of rust occurrence	The ratio of the area of average rust occurrence (%)	Rank of rust occurrence
Beach side	A	1	0	A	0.005	A	0	A
		5	13.3	D	11.6	C	8.8	C
		10	40.0	E	24.8	D	28.3	E
	B	1	0	A	0	A	0	A
		5	5.9	C	2.4	B	1.2	B
		10	4.0	C	8.0	C	3.1	C
	C	1	0.003	A	0	A	0.01	A
		5	34.3	E	16.4	D	13.7	D
		10	39.7	E	21.8	D	30.9	E
Roof top	A	1	0	A	0	A	0	A
		5	0.9	A	0.5	A	0	A
		10	0	A	0	A	0	A
	B	1	0	A	0	A	0	A
		5	0.04	A	0.02	A	0	A
		10	0.05	A	0.2	A	0	A
	C	1	0.01	A	0.03	A	0.005	A
		5	2.6	B	0.6	A	0.02	A
		10	0	A	0	A	0.02	A

TABLE 8--LIST OF CLASSIFIED RANK

Rank of rust occurrence	Ratio of the area of rust occurrence	Conditions of rust
A	0 ~ 1.0	Slight scattered of rust
B	1.0~ 2.5	The scattered rust is in progress and will be reached to the area of rust
C	2.5~10	Full-scale rust is in progress and it occupies to a certain extent
D	10 ~25	Part of rust is in progress until the surface of reinforcing bars from 1/10 to 1/4
E	25 ~50	Rust occurrence on the surface of reinforcing bars from 1/4 to 1/2



NW-40 : Normal Portland cement, W/C = 40%, Mixing water=drinking water.
SW-40 : Seawater resistant cement, W/C = 40%, Mixing water=drinking wat
3 W : Immersion in water for 3 days.
3 S : Immersion in seawater for 3 days.
28 S : Immersion in seawater for 28 days.

Fig. 1--Test result of accelerated deterioration

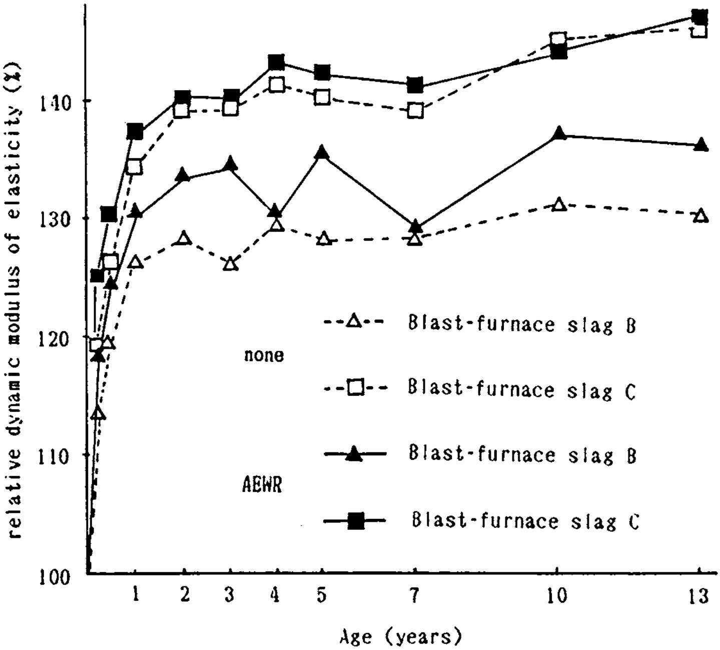


Fig. 2--Relationship between the age and relative dynamic modulus of elasticity of concrete in sea water

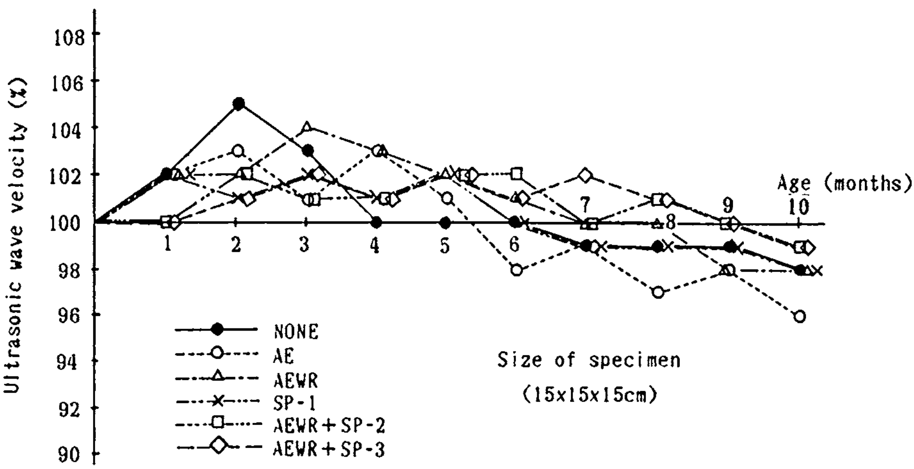


Fig. 3--Relationship between age and ultrasonic wave velocity ratio of concrete immersed in sea water

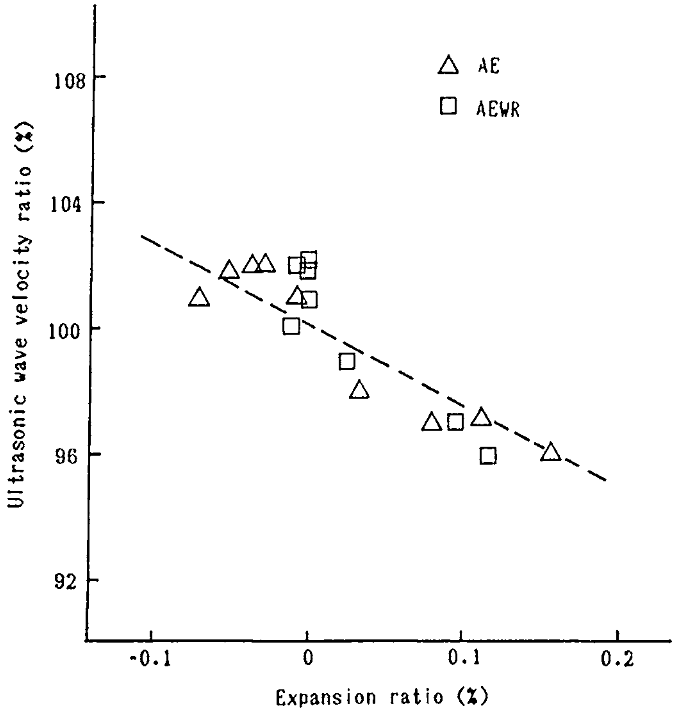


Fig. 4--Relationship between expansion and ultrasonic wave velocity

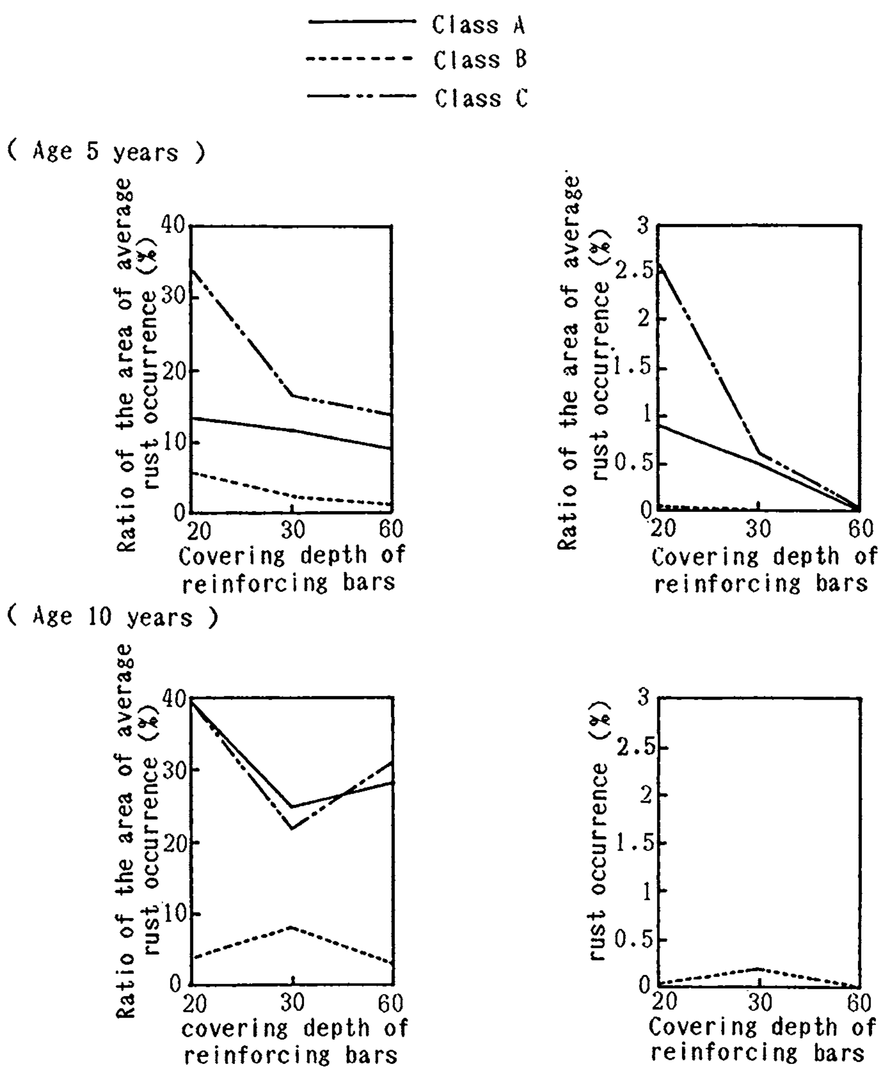


Fig. 5--Beach side

Fig. 6--Roof top

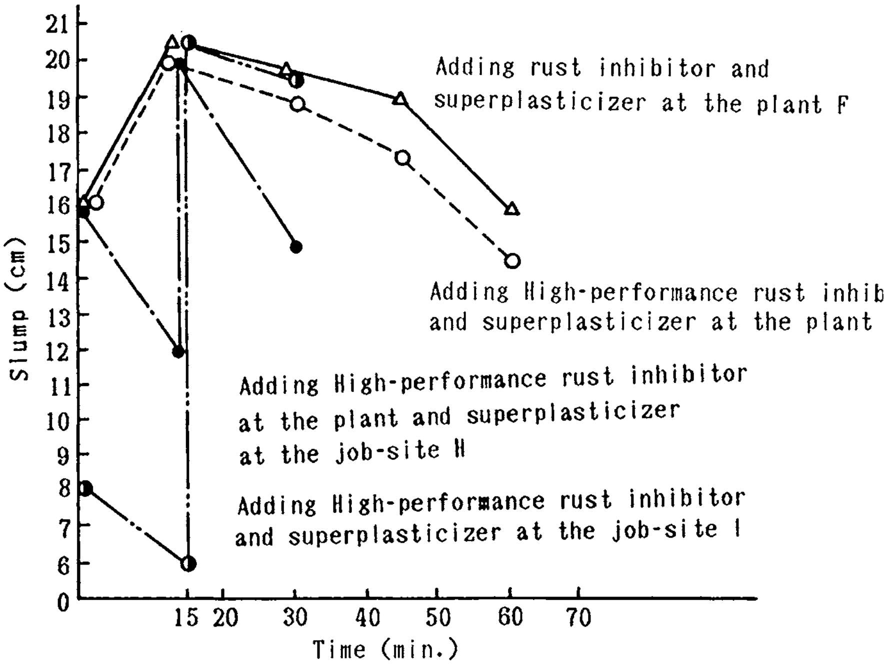


Fig. 7--Slump loss of concrete contained high-performance rust inhibitor

SP 109-22

Mix Design and Strength Data for Concrete Platforms in the North Sea

by A.K. Haug and M. Sandvik

Synopsis: Since 1971 Norwegian Contractors has produced approximately 1.3 million cubic meters of high quality concrete for offshore platforms in the North Sea. To meet the development in structural design and construction methods a continuous effort has been made to advance the concrete mix design process. The paper gives a survey of the research work in this process.

The mix design has to take care of several contradictory requirements, such as high strength and low permeability on one side and moderate heat develop- ment and extraordinary workability on the other. From 1972 to 1986 the concrete grade has been increased from C45 to C70 while the workability (slump) has been increased from 120 to 240mm mainly due to extreme dense reinforcement (above 1000 kg/m^3 in local areas). During the last years more automated and efficient construction tools have been introduced, applying further demands on the constructability of the fresh concrete mix.

The chemical composition of the cement is aimed at an optimized 28 days compressive strength with moderate heat development. In addition the setting time has been reduced by an increased grain fineness.

The fine aggregates are produced through a hydraulic process to obtain the desired particle distribution. Minor changes in the finer part of the grading has resulted in remarkable improvements in the workability and pumpability by stabilizing the paste-aggregate matrix.

Different chemical admixtures are essential constituents to obtain the desired workability of flowing concrete and for control of the setting time during huge slipforming operations.

The practical use of very high strength normal density concrete (C80-C100) and high strength concrete with lightweight aggregates are new challenges for the concrete mix design so as to satisfy new advancements in construction methods.

Keywords: admixtures; air entrainment; compressive strength; fine aggregates; heat of hydration; high-strength concretes; lightweight aggregate concretes; mix proportioning; offshore structures; permeability; setting (hardening); slipform construction; workability

Atle K. Haug is Director of the Quality Control Department, Norwegian Contractors. Malvin Sandvik is a Specialist Engineer at Structural Design Department, Norwegian Contractors.

INTRODUCTION

The service reports from the up to 15 years old concrete platforms in the hostile environment of the North Sea are confidently positive. The need for remedial work is a minimum and demonstrate the excellent performance of high quality concrete under marine conditions. Fig. 1. shows Condeep TPC-2 exposed to a 100 year storm with 26 m wave height in 1981.

In Norwegian Contractors concrete mix design research and development has been a major challenge even from the start in 1971 with Ekofisk 1 until today after producing some 1.3 mill. m^3 of high quality concrete for 13 offshore projects (Fig. 2). The largest one, Gullfaks C, is still under construction and will contain approximately 240.000 m^3. Table 1 shows all the 19 concrete platform projects for the North Sea.

Concrete mix design plays an important role in offshore platform projects due to the very high strength, durability, and workability requirements, the magnitude of the structures, and the rate of construction (1,2).

An essential part of the knowledge used in the research work is practical experience obtained during the construction. Through the comprehensive records of test results and detailed observations from the site supervision experience of great value is acquired and applied in the practical development work.

In this report a summary of significant steps in the concrete mix design development is described. Special attention is paid to quality improvements of the concrete constituents and the constructability properties of the fresh concrete. A major part of the presented test results originates from the huge cell walls slipform operation of the Gullfaks C platform (115.000 m^3 of concrete) and the shaft slipforming of the Oseberg A platform (air-entrained concrete).

The paper makes also a brief reference to the development of high strength concrete with light weight aggregates and finally the need for further research and development work within the field of practical concrete technology.

QUALITY REQUIREMENTS

The basic demands upon concrete for the North Sea are founded on durability and are in general the same today as in the 1970's, modified through the years by major developments in design and construction methods. The quality requirements of the concrete can be divided into three categories:

CHALLENGE	PARAMETERS
Specified concrete grade Normal density concrete:	Compressive strength E-modulus Tensile strength
1970's: C45-C55 1980's: C55-C70 (1990's: C80-C100?)	Stress-strain relations Ductility In situ strength
LWA concrete: C55-C70	Density < 1900 kg/m^3
Corrosion and chemical attack	Sound constituents Low permeability (k $< 10^{-13}$ m/sec.) Low w/c ratio (Submerged zone: < 0.45 Splash zone : < 0.40) Minimum cement content (350 kg/m^3) Adequate cover to reinforcement (Min. 50 mm)
Frost resistance (Splash zone)	Air entrainment (A = 3-5 %, $\alpha > 25$ mm^2/mm^3 and $\bar{L} < 0{,}25$ mm)
Dense reinforcement and embedments	High workability (Slump: $>$ 220mm) No bleeding or separation
Slipforming	Ajustable and predictable setting time Revibration
High production rates and advanced conveying systems	Consistent quality of constituents Controlled batching and distribution
High pressure pumping	High pumpability Concrete temperature
Large dimensions	Cement content/heat of hydration Cooling of fresh concrete Insulation of hardened concrete

<u>Constructability:</u> The ability of the fresh concrete to satisfy the construction methods.

During the last years the requirements for durability and strength have been met with ample margins. Considerable effort has, however, been applied to the constructability of the concrete as more efficient production with significant positive cost impact has been encountered.

CONCRETE MIX DESIGN DEVELOPMENT

Some typical milestone developments in mix design are shown in Fig. 3. It can be seen from the data that in spite of an apparently unchanged w/c ratio, an increased strength (by some 45 %) is achieved since the middle of the seventies.

The need for more workable mixes during the period is noticeable. This is mainly brought about by extremely dense reinforcement (up to 1000 kg/m^3 in local areas) and new construction methods.

The improved concrete properties are mainly a consequence of improved cement qualities, more efficient admixtures (from lignosulphonates to naphtalenes and melamines) and better controlled processing of aggregates. By these means it has been possible to obtain considerably improved strengths and constructability whilst maintaining low w/c ratios and, relatively speaking, low cement contents.

CONCRETE CONSTITUENTS

Cement

Up to 1978 ordinary portland cement (OPC) was used for the offshore platforms. In response to the higher concrete strength requirements and developments in the design process a new cement was developed. The cement designated SP30-4A was introduced in 1978.

Typical properties for the SP30-4A cement were high long term strength and moderate heat of hydration. An increased setting time and a decrease of early strength were, however, serious disadvantages during some slipform operations where a slip rate of at least 3 metres a day was desirable.

In order to achive a reduced setting time and increased early strength a further development of the SP30-4A cement took place and a modified cement version designated SP30-4A MOD was introduced in 1981. Typical data for the cements in question are shown in Table 2.

From Table 3 it can be observed that the development has approached a cement with an optimized 28 days compressive strength, but still having a certain increase in long term strength. A moderate heat of hydration in proportion to the strength is a result of this approach (3).