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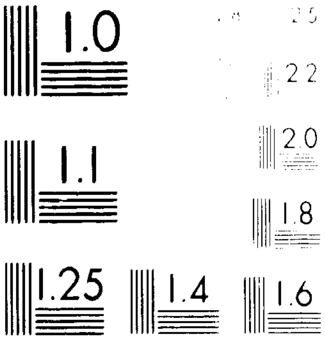
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UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

ASSISTANCE TO THE LIBYAN CEMENT FACTORY, BENGHAZI

TF/LIB/75/002

LIBYAN ARAB JAMAHIRIYA

Libya. Mission report: Feasibility of producing sulphate-resisting cement

Prepared for the authorities of the Libyan Arab Jamahiriya
by the United Nations Industrial Development Organization

Based on the work of A.R. Marei, project co-ordinator

V.81-31572

Explanatory notes

The monetary unit in the Libyan Arab Jamahiriya is the Libyan dinar (LD). During the period covered by the report, the value of the Libyan dinar in relation to the United States dollar was $US 1 = LD 0.296.

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions.

References to "tons" are to metric tons.

In tables, a dash (-) indicates that the amount is nil or negligible.

The following abbreviations of organizations are used in this report:

ASTM	American Society for Testing and Materials
CERIC	Centre d'étude et de réalisation industrielle et commerciale
KHD	Kloeckner Humboldt Deutz, Industrieanlagen AG
LCC	Libyan Cement Company

The following technical abbreviations are used in this report:

AM	alumina modulus
C_2S	dicalcium silicate
C_3S	tricalcium silicate
C_3A	tricalcium aluminate
C_4AF	tetracalcium aluminoferrite
DTA	differential thermal analysis
LOI	loss on ignition
LSF	lime-saturation factor
SM	silica modulus
SRC	sulphate-resisting cement
XRDM	X-ray diffraction method

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ABSTRACT

This project, "Assistance to the Libyan Cement Factory, Benghazi" (TF/LIB/75/002), is being carried out for the authorities of the Libyan Arab Jamahiriya by the United Nations Industrial Development Organization (UNIDO) under a trust-fund agreement. The project, which has been in operation since 1975, represents a new form of technical assistance with direct support to industry. The expert took over as co-ordinator of project activities in May 1980.

The main object of this feasibility study was to investigate the possibility of the Libyan Cement Company (LCC) introducing the production of sulphate-resisting cement using mainly local raw materials.

The report traces the development of sulphate-resisting cements (SRC) and gives their chemical and physical properties and the standard specifications for different types of SRC. The location, suitability and availability of the raw materials needed for SRC production are investigated and the calculations for trial raw-mix designs are given. It is concluded that the production of SRC by the Libyan Cement Company would be feasible from both the technical and the economic point of view and without requiring major alterations to the machinery and production processes already used to produce normal portland cement.

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INTRODUCTION

This project, "Assistance to the Libyan Cement Factory, Benghazi" (TF/LIB/75/002), is being carried out for the authorities of the Libyan Arab Jamahiriya by the United Nations Industrial Development Organization (UNIDO) under a trust-fund agreement. The project, which has been in operation since 1975, represents a new form of technical assistance with direct support to industry. The expert took over as co-ordinator of project activities in May 1980.

The main object of this feasibility study was to investigate the possibility of the Libyan Cement Company (LCC) introducing the production of sulphate-resisting cement using mainly local raw materials.

A separate feasibility study on this topic was submitted in Arabic to the LCC in March 1981 which also dealt with the introduction of sulphate-resisting cement in the Alexandria Portland Cement Company based on the various raw materials available in the vicinity of Alexandria. The present report is a shorter version of the feasibility study in Arabic, including only the material relating to the expert's activities in the Libyan Arab Jamahiriya in connection with the Libyan Cement Company.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. It is quite feasible to produce sulphate-resisting cement (SRC) either in the Benghazi area or in cement plants in the western part of the country where sufficient amounts of the necessary raw materials are available.

2. The limestone and marl from the Benghazi area proved suitable for this type of cement production. Large reserves of the best siliceous sand were found 90 kilometres south of Ajdabiyah.

3. In testing many raw-mix designs, it was found that it is possible to produce SRC Type II (ASTM, C-150) by adding only iron ore or pyrite ash to the normal portland cement raw mix used by the LCC. Type V (ASTM, C-150) can be produced by using four components, limestone and marl (from the Hawari quarry), sand (from the Gialo region) and either iron ore (from the Sabhah area) or pyrite ash, which can be cheaply imported from neighbouring countries.

4. It would be economically feasible for the LCC to produce this type of cement as the cost of production would be LD 10 per ton less than the cost of imported SRC.

5. It is possible to produce SRC with the same production-line equipment and processes as for normal portland cement and with very little change in handling the raw materials.

Recommendations

1. Production of SRC should be introduced in either the Benghazi production line I or II, or both, according to the country's total requirement for SRC.

2. It is recommended that the two types of clinker should not be mixed and that, accordingly, the clinker silos in the Benghazi plants should be reserved for SRC production.

3. After a visit to the Al-Khums I Cement Plant, the expert recommended the use of this plant for SRC production because of the suitability of its raw materials.

4. The production of SRC with less than 3% C_3A is recommended. (In LCC it ranges from 12-15%.) This would completely solve the problem of the formation of lumps and aggregation in the cement silos.

I. THE DEVELOPMENT OF SULPHATE-RESISTING CEMENTS

A. Historical background

Dr. Thorvaldson's life-work was devoted to the study of the properties and processes of cement and its compounds, his greatest achievement being the experimental demonstration of concepts which led directly to the development of a sulphate-resisting cement. By 1918 in western Canada, the destructive action of alkaline ground waters on concrete structures was generally recognized by engineers to be a problem of major importance. Between 1918 and 1920, no comprehensive plan was developed to carry out organized research on the problem. In Saskatoon in 1919, Dr. C.J. Mackenzie of the Engineering Department of the University of Saskatchewan began some exposure testing in the field.

The early chemical work done by Dr. Thorvaldson involving tests of soils and ground waters and observations on associated field exposure tests, led him to three main conclusions:

(a) The variation in the concentration of sulphate in the ground water could have been a major factor in the variability noted in some field exposure tests;

(b) $MgSO_4$ is more soluble than Na_2SO_4, particularly at low temperatures;

(c) Lean concretes were found to disintegrate rapidly when surrounded by disintegrated concrete and pure water. This indicated the presence in affected concrete of excessive amounts of sulphates.

In June 1922, Dr. Thorvaldson succeeded, with the assistance of Dr. G.R. Shelton, in preparing the pure cement compounds known as tricalcium silicate (C_3S), dicalcium silicate (C_2S), and tricalcium aluminate (C_3A). These compounds were characterized and their reactions in pure water and in sulphate solutions were studied, mainly by microscopic methods. The main conclusions were:

(a) The formation of calcium sulphoaluminate is due to the reactions between hydrated C_3A and solutions of Na_2SO_4 in all concentrations, and $MgSO_4$ in low concentrations;

(b) With more concentrated solutions of $MgSO_4$, $Mg(OH)_2$ was present and this tended to retard the formation of calcium sulphoaluminate;

(c) $MgSO_4$ appeared to have a generally more destructive effect than Na_2SO_4 on the hydrated C_3A and also on portland cement.

Dr. Thorvaldson recognized that the remedy would probably lie in the modification of the chemical composition of cement. He developed the lean-mortar bar test and, by means of it, demonstrated directly the role of C_3A among the pure compounds in producing excessive expansion in mortars and concretes. His conclusion that the C_3A content could be reduced by formation of tetracalcium aluminoferrite (C_4AF) was tested in the plant, Burns, and resulted in the modern sulphate-resisting cement.

B. The chemistry of sulphate-resisting portland cements

As in scientific progress in general, so in the case of portland cement, the finally-accepted theory is the result of the efforts of several people. Impure limestones, when calcined, were discovered to yield products that behaved differently in their reactions with water from the products obtained when pure limestones were calcined. Studies of these impure limestones led to the development of portland cement. The history of this development has been reviewed by Bogue.

Having discovered that cements could be prepared by calcining blends of calcareous, argillaceous, and siliceous materials, investigators were faced with the problem of explaining what happened during calcination and during the reaction of the calcined product with water. While they were busy with these problems, engineers discovered that products made of portland cements did not always perform satisfactorily when exposed to saline waters. This opened up a new field of research. The literature on the development of sulphate-resisting cements has been reviewed elsewhere. Here, we will deal only with the subject of why concrete is attacked by saline waters and why certain cements produce concretes that have a relatively high resistance to attack by these waters. Included in this is an outline of the several mechanisms by which concrete can be attacked by salts and through which the substitution of calcium aluminoferrite for tricalcium aluminate increases the sulphate resistance of cements.

A number of early investigators, Lea, Le Chatelier and Desch used the microscope in an effort to determine the chemical composition of the compounds present in hydraulic limes and portland cement.

Hansen, Brown, Miller and Bogue studied the system calcium oxide-alumina-iron oxide (CAF).

Thorvaldson, Vigfusson and Larmour studied the behaviour of mortar bars of the following compositions in water and solutions of calcium and magnesium and sodium sulphates:

1 part C_3S + 5 parts sand
1 part C_2S + 5 parts sand
1 part C_3S + 0.25 parts C_3A + 5 parts sand
1 part C_2S + 0.25 parts C_3A + 5 parts sand
0.53 parts C_3S + 0.26 parts C_2S + 0.21 parts C_3A + 7.5 parts sand

In 1926, the Portland Cement Association Fellowship at the National Bureau of Standards began an extensive investigation of the volume stability of 1:2 mortar bars made with pure compounds, cement prepared in a small experimental kiln, and commercial cement stored in water and in sulphate solutions.

The results of the above studies clearly indicated that cement with a relatively high resistance to sulphate could be prepared by decreasing the A/F ratio of the clinker, either by decreasing the alumina content of the kiln feed or by adding additional iron-bearing material to it, both of which reduce the potential C_3A content of the clinker. European investigators had also reached the conclusion that C_3A was the least resistant of the cement minerals to attack by sulphates. There is a definite relationship between calculated C_3A content and sulphate-resistance. Miller and Manson modified the composition of some kiln feeds so as to decrease the potential C_3A content and to increase the potential C_4AF content. These cements showed a resistance to sulphate much improved in comparison to that of the modified cements.

A number of investigators have attributed the deterioration of concrete in sulphate-bearing water to the formation of ettringite. This compound was prepared by Candlot (1890) by the interaction of aqueous solutions of calcium aluminates and calcium sulphate. Most investigators have assumed that, since this highly hydrated salt occupies much more volume than the C_3A from which it formed, its formation by a **diffusion process in the** pores of the concrete would cause expansion and destruction of cement paste.

Lerch, Ashton and Bogue showed that C_3A formed two compounds with calcium sulphate that were stable in aqueous solutions saturated with $Ca(OH)_2$, i.e. ettringite, a high-sulphate form, and monosulphate or low-sulphate form, $C_3A.CaSO_4.13H_2O$.

Malquori and Cirilli, McIntire and Show prepared the high-sulphate iron compound, $C_3F.3CaSO_4$.aq. and Malquori and Caruso prepared the low-sulphate iron compound, $C_3F.CaSo_4$.aq. Malquori and Cirilli demonstrated the existence of a series of solid solutions between the high-sulphate aluminate and the high-sulphate ferrite compounds as well as a series of solid solutions between the low-sulphate aluminate and the low-sulphate ferrite compounds. They studied the sulphate resistance of some of their products by determining the rates at which the products combined with sulphate in a solution saturated with respect to both $Ca(OH)_2$ and $CaSO_4 2H_2O$. With C_3A.aq. and C_4A.aq. the ratio of SO_3/R_2O_3 in the solid reached 3 in 15 days, whereas with a solid solution in which the A/F ratio was 3, the SO_3/R_2O_3 ratio was 1.3 at 15 days and 2.4 at 60 days compared with 0.5 and 1.3 for a solid solution with an A/F ratio of 1 and with ratios of 0.4 and 0.9 for C_4AF.aq.

One of the conclusions of these studies was that C_3A reacted with water and calcium sulphate in three stages as follows:

(a) Stage I. C_3A combines with water and calcium sulphate to form ettringite. This stage terminates when the gypsum is depleted;

(b) Stage II. C_3A reacts with water and ettringite to form calcium monosulphate, $C_3A.CaSO_4.14\text{-}15H_2O$;

(c) Stage III. Remaining C_3A reacts with water, monosulphate and $Ca(OH)_2$ to form a solid solution of $C_4A.aq.+Ca(OH)_2$.

Similar pastes in which the ferrites replaced C_3A showed that the reaction of the aluminoferrites with water and sulphate was relatively slow. It was concluded that C_4AF not only reacts much more slowly than does C_3A but that the aluminoferrite phase retards the normal reaction of stage I for C_3A. In all cases, the reaction behaviour of the mixtures containing the aluminoferrites corresponded to the three stages found for the C_3A pastes, but the reactions occurred at slower rates.

A number of investigators have presented data which show that curing concrete or mortar specimens at temperatures at or above 100°C under pressure greatly increases their resistance to attack by sulphates regardless of the C_3A content of the cement. These are the conditions that would convert C_3A and aluminoferrite to hydrogarnets which, as shown by Flint and Wells and by Schwiete and Iwai, are highly resistant to attack by sulphates.

II. AVAILABILITY OF RAW MATERIALS

The production of normal portland cement clinker at the Libyan Cement Company (LCC) relies mainly on raw materials predominating in the Hawari area near Benghazi. The raw materials are limestone and marl. Accordingly these raw materials will be used as the main components of the raw-mix designs as shown later.

A. Limestone and marl

Topography and geological features of the Hawari area

The area which supplies the LCC's production of normal portland cement lies about 8.5 kilometres south-east of Benghazi city. The Benghazi - Suluq road runs through this area.

The Benghazi plain rises towards the east to about 150 metres above sea level. Inland, it is bounded by the first relatively low cuesta of the Cyrenaica which has a relative difference in elevation of about 100 metres.

The strata forming the hills around Benghazi city are formed mainly of carbonate rocks of the Al-Rajmah formation (Middle Miocene) which is sub-divided into two members, the lower "Benghazi" member (150 to 200 metres in thickness) and the upper "Wadi Al Quattarah" member (about 50 metres in thickness) with intercalations of gypsum near Rajmah.

The strata are nearly horizontal with a general dip of a few degrees towards the east. The strata are slightly disturbed by vertical faults. The transitional boundary between the "Benghazi" member and the "Wadi Al Quattarah" member is smooth. The transition (from hard step-forming limestone to the soft carbonate rocks) is exposed in the upper part of the above-mentioned cuesta. The Tertiary formations are more or less completely covered by the Quaternary. These are, above all, shore sands (calcareous) and residual loams.

According to the latest geological mapping carried out by a Czechoslovak company, the limestones of the investigated area belong to the Al-Rajmah formation.

The strata of the investigated area lies within the range of a reef-core facies built up by coral colonies, with fossil debris and cavities up to the size of a child's head. The cavities are partly filled with calcite crystals or incrustated fossils. These cavities are not limited to definite layers, as can be seen from the cross sections. The coral colonies are more frequent in the borings near the existing quarry than in the borings at a distance of about 2-3 kilometres, which indicates the limitation of the reef core.

The upper part of the limestone series is composed of 2-4 metres of thick, light gray to gray fossil-bearing limestone. The Tertiary limestone series is covered by Quaternary sands, gravel, caliche and residual marl. The latter has the greatest regional extension and is the most significant clay component used in the cement industry in this area. The clays are of strong, red-brown colour and belong to the terra rossa formations which are characteristic of subtropical climates and predominate all over the Mediterranean area.

Marl is the main component required for the LCC's normal portland cement raw meal together with the silica, alumina and iron components. Marl is usually represented as loose rock. Petrographically, it is formed of a detrital part and a microcrystalline part. The first part is formed of oolites and microcrystalline calcite and/or aragonite and dolomitic fragments in a matrix of partially silicified carbonate quartz as sand grains, fine to very fine, angular to subangular. Feldspar crystals are also usually prese[nt]. The clayey material forming the second part is represented as dispersed matter consisting of micaceous clays and limonitic substances. The thickness of this soil varies between 2.5 and 6.5 metres in the investigated area and increases towards the east. Scattered intercalations of sand, gravels, and limestones (0.1-1.5 metres in thickness) with many fossils can be observed.

There are two explanations for the origin of the intercalated limestones in the clayey marls. They either consist of blocks of limestone which have been transported (not necessarily a long distance), or they are traceable to irregular weathering of the surfaces of limestones in situ.

They have been found only in a few borings, which does not suggest a notable regional extension. There is a conspicuous occurrence of marl at 12 metres and from 29 metres on in boring CH-5. This can only be attributed to a fissure in this area which is to be observed from 29 metres on. A core loss of 2.5 metres was observed on this level in CH-3. It is noteworthy that gravel (probably from a river) occurs above all in the borings CH-5 and CH-17. For the distribution of red clay and of the test-boring drill holes, see figure I.

Chemical evaluation

The chemical analyses of the limestone showed that it is a high-grade material with a $CaCO_3$ content ranging between 91 and 97%. The chemical-analysis results are summarized in tables 1 and 2 and are given in detail for each of the test borings CH-1 to CH-17 in annex I. According to these analyses, the material is suitable for the production of cement with few exceptions. In some borings, the MgO and chlorine content turned out to be considerable. This increased percentage of undesirable constituents has to be made good by prehomogenizing this raw material with another one whose MgO and chloride content is lower. This applies above all to borings CH-4, CH-5, CH-8, CH-3 and CH-2. The analyses show that dolomitization is irregular and decreases towards the west. The chloride content varies both in the clayey marl and in the limestone. Values from traces up to 0.35% have been observed. The SO_3 content is very low with the exception of a very few samples. The chlorine content ranges from 0.02-0.05%.

As to the clayey marls, the uppermost layer from 0 to 1 or 2 metres in depth was analysed separately as this is an inhomogeneous but nevertheless suitable material shot through with limestone debris. The results of the complete analyses show that the raw materials are suitable for the production of cement.

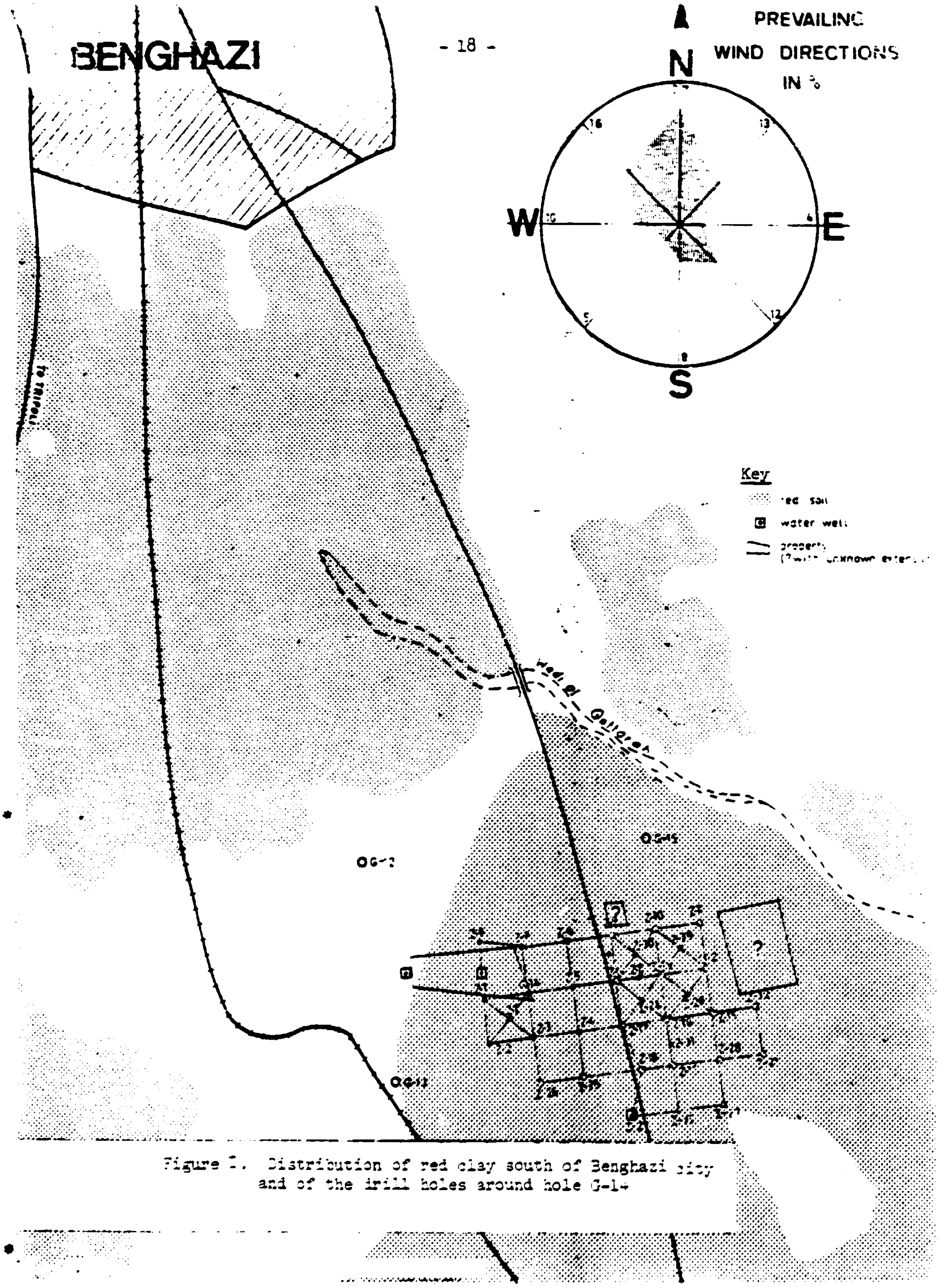


Figure 1. Distribution of red clay south of Benghazi city and of the drill holes around hole G-14

Table 1. Mineralogical composition of red clay and limestone from the Benghazi area

Sample No.	CA-Mat.No.	DTA No.	XRDM No.	Titration	Clay minerals					QUARTZ	FELDSPAR	CALCITE	DOLOMITE	Remarks
					KAOLINITE	ILLITE	MONTMORILLONITE	MIXED LAYERS	PALYGORSKITE					
Z-5, Zr 37	6671/A	2390/4	4504	37.3	o	o	-	o	o	xxx	x	xx	tr	red clay
	6671/A/S	2393/4	4514	-	oo	o	-	oo	o	xxx	x	-	-	
Z-16, Zr 88	6722/A	2390/3	4505	43.0	o	o	-	tr	tr	xxx	x	xxx	tr	
	6722/A/S	2393/3	4515	-	oo	o	-	oo	o	xxx	x	-	-	
Z-11, 0-7,15m	6908/A	2390/2	4506	47.0	o	o	-	o	-	xx	tr	xxx	-	
	6908/A/S	2393/2	4513	-	oo	o	-	oo	o	xxx	x	-	-	
Z-5, Zr 38-43	6901/A	2391/2	4507	92.4	-	-	-	-	-	tr	tr	xxxx	x	limestone
	6901/A/S	2392/2	4510	-	oo	o	-	o	o	xxx	xx	-	-	
Z-11, 7,15-31m	6902/A	2391/3	4508	96.8	-	-	-	-	-	-	-	xxxx	xx	
	6902/A/S	2392/3	4516	-	oo	oo	ooo	-	-	xx	x	-	-	
Z-28, Zr 131-36	6906/A	2391/4	4509	93.6	-	-	-	-	-	tr	-	xxxx	x	
	6906/A/S	2392/4	4512	-	oo	o	-	oo	-	xxx	x	-	-	

Key:
crystallinity
o moderate
x differentiation not possible

The number of symbols represent the relative quantitative mineral content:
4 symbols = predominant
3 " " = considerable
2 " " = moderate
1 symbol = insignificant
tr = traces
- = none

Minerological composition of the limestone and marl

Table 1 shows the mineralogical examination by the differential thermal analysis (DTA) method, and the x-ray diffraction method (XRDM).

All samples, limestone as well as red clays, show a very similar mineralogical content. This fact was to be expected, especially if it is understood that marl is formed through a partial decarbonization of residual clay-rich soil, mostly derived from the same limestone province.

Moisture content

To determine the moisture content of the limestone and marl *in situ*, a ditch of approximately 13 metres in depth was dug near to borehole Z. The results of the investigation are shown in table 2.

Table 2. Moisture content of limestone and clay at various depths

Type of soil/rock	Depth (metres)	Humidity (percentage)
Red clay (marl)	0.2	16.1
	1.0	9.5
	2.0	10.3
	3.0	8.9
	4.0	12.8
	5.0	9.6
	5.5	11.1
	5.7	9.1
Limestone (hard)	7.0	1.7
	8.0	2.0
Limestone (chalky)	8.9	4.5
	9.8	4.8
	10.7	2.9
	11.6	2.9
	12.3	3.9
	12.5	3.9

Limestone and marl reserves

As shown by the chemical analyses, the limestone, originating from a reef complex and varying in its MgO content, is suitable for the production of cement. If all the material from the deposit is well homogenized before its introduction into the clinker raw meal, those parts of the deposit which have a higher MgO content can be used as well. Therefore, they can be included in the overall assessment of the reserves.

The limestone relative density, when calculating the limestone reserves, was assumed to be 2.5. The limestone depth was assumed to be 40 metres for quarrying purposes. According to these assumptions, the total reserves of limestone in this area would be around 213.5 million tons of limestone.

For the marl, the average thickness was assumed to be 5 metres. The marl relative density was assumed to be 2.0. Accordingly, the total marl reserves in this area would be about 44.8 million tons. It is worth mentioning that the deposits of these raw materials (i.e. limestone and marl) extend over large areas and these other areas can be investigated in the future when further reserves need to be exploited.

B. Ajdabiyah sand

All the geological studies and investigations carried out by the French company, CERIC, failed to reveal any siliceous sand resources between Benghazi and a point 90 kilometres south of Ajdabiyah.

These studies indicated that sedimentary rocks of carbonated origin spread all over the area surrounding Benghazi city, especially to the north and north-east. These rocks are covered with what is known as terra rosa sediments.

CERIC discovered huge amounts of siliceous sands in an area along the Ajdabiyah-Gialo road as shown in figure II. The best siliceous sand resourees were found to be located 90 km south of Ajdabiyah along the road to the Gialo oasis.

The oligo-miocene limestone rocks are covered with a sand stratum of a regular thickness of 10 metres which contains in its lower parts silicified wood. The silica sands are formed mainly of siliceous materials (quartz and quartizitic rocks). The mechanical analyses of some sand samples are shown in table 3.

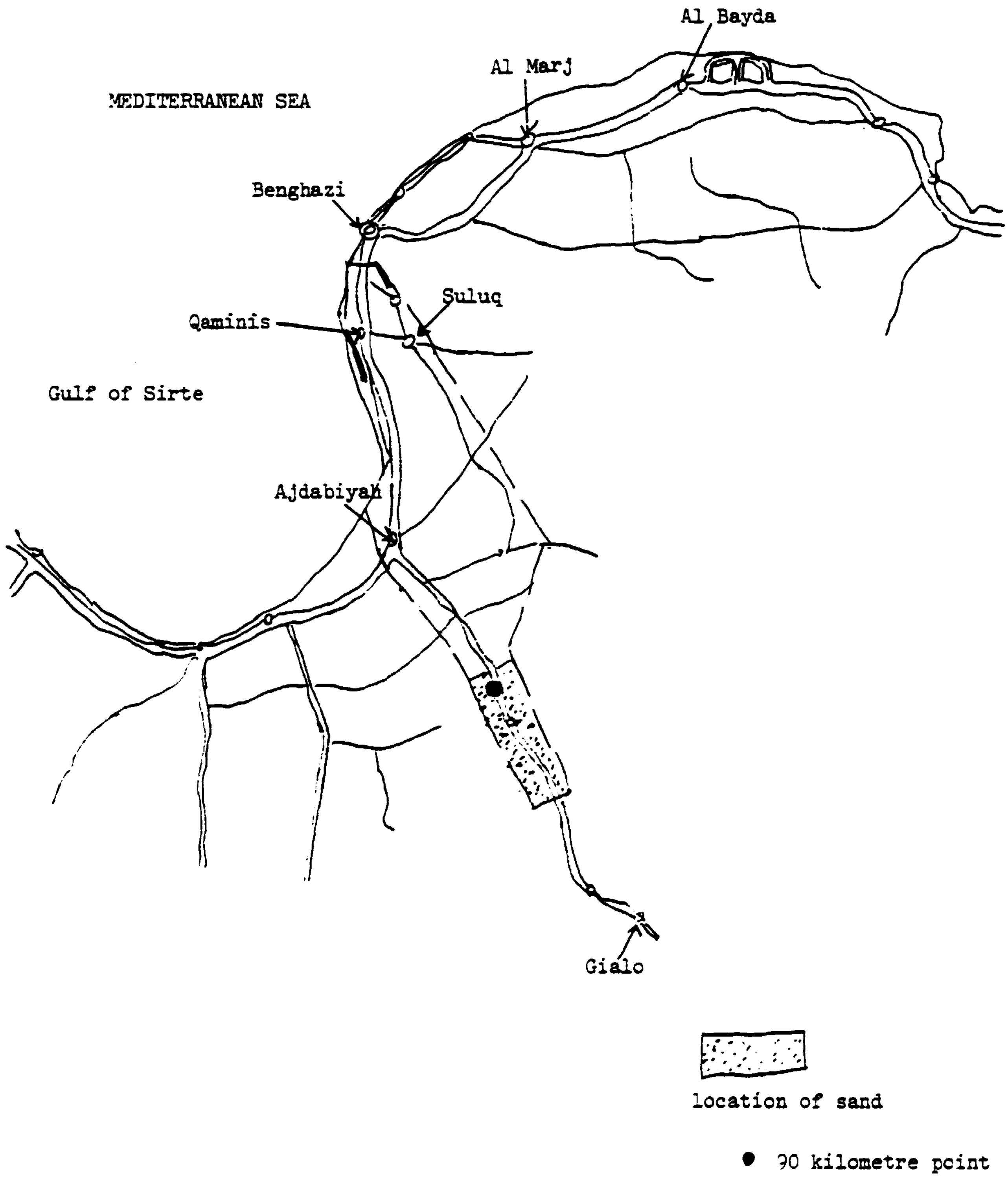


Figure II. Location of siliceous sand south of Ajdabiyah

Table 3. Carbonate content and mechanical analyses of some sand samples

Sample No.	Distance from Ajdabiyah (kilometres)	$CaCO_3$ (percentage)	Grain size (μm)		
			100 (%)	100-250 (%)	250-2000 (%)
1	90	1.5	2	20	8
2	90	22.5	8	32	60
3	115	4.50	6	26	68
4	130	1.75	7	20	73
5	163	5.00	14	35	51
6	205	12.25	10	27	63
7	255	4.5	8	22	70

The biggest grains in the siliceous sands investigated were 5 millimetres in size. The sand grains appear dull, roughly spherical with some rounded grains. The silty portion ranges in colour from beige to yellowish. The calcareous grains look dull, are spherical in shape and their grain size is up to 0.5 a millimetre.

Exploitation of the sand reserves

The CERIC report said that at present the working face of the quarry at the 90 kilometre point is 3-4 metres high. It was suggested that excavation should progress horizontally until the Miocene substratum consisting of green marls (facies of decalcification of the Miocene limestone) is reached. Later on, excavations will progress southwards until they meet up with the excavations carried out for the embankment of the Ajdabiyah-Gialo road. The underlying green-marl stratum shows a perfect horizontal contact surface with the overlying sand stratum. This means it will be very easy to extract the sand, now and in the future. The reserves of this sand are endless. The report said nothing about the chemical composition of the siliceous sands. Therefore, a representative sample was taken from the stockpile of sands in the brick plant. Another representative sample of the calcareous sands (from Sidi Khalifa), also piled in the same plant, was taken. The two samples were chemically analysed. Table 4 shows the chemical composition of these two representative samples.

Table 4. Chemical composition of Sidi Khalifa and Ajdabiyah sa (percentage)

Component	Sand samples	
	Ajdabiyah-Gialo	Sidi Khalifa
$CaCO_3$	15.75	96
SiO_2	71.02	0.01
Al_2O_3	2.75	1.35
Fe_2O_3	traces	traces
CaO	8.83	56.3
MgO	1.4	--
SO_3	0.4	0.35
Cl	traces	--
Loss on ignition	8.15	44.09

Note: The chemical analysis was carried out in the Libyan Cement Company's laboratory.

C. Addition of siliceous and ferriferous materials

One of the main sources of raw materials used at present for the production of normal portland cement at both the Hawari and Benghazi Cement Plants (LCC) is the Hawari quarry from which limestone as well as marl is extracted.

The preliminary calculations for a SRC raw-mix design using these materials showed that the mixture is deficient in silica as well as iron-oxide content. Accordingly, materials rich in silica (siliceous) and in iron-oxide (ferriferous) content must be added. As shown in the last section, siliceous material can be obtained from the sand dunes predominating along the Ajdabiyah-Gialo road.

The iron ore (ferriferous material) can be supplied either from the local iron-ore rich deposits near Sabhah (Galmoya iron ore) or from pyrite ash (by-product of sulphuric-acid production) which can be imported from neighbouring countries like Greece or Italy. Both ferriferous materials were used in calculating our raw-mix designs.

A sample of Galmoya iron ore was obtained and analysed in the LCC laboratories. Subsequently, we received two reports evaluating the deposits of cement raw materials at Ash Shati and Al Jufrah. The two reports indicated that the mean chemical analysis of Galmoya iron ore is as follows:

	percentage
Loss on ignition (LOI)	14.0
SiO_2	4.7
Al_2O_3	3.5
Fe_2O_3	71.0
CaO	2.8
MgO	1.5
SO_3	0.1
Cl	0.42

When this study started in September 1980, there was no pyrite-ash sample available to analyse. Accordingly, it was assumed in this study that the chemical analysis of pyrite ash to be applied in our raw-mix-design calculations would be that indicated in the Holderbank report on the Benghazi Cement Plant, October 1967. The chemical analysis of pyrite ash (Attisholz C.A. Mat. No. 5244/A) given in that report is:

	percentage
LOI	3.4
SiO_2	5.25
Al_2O_3	5.95
Fe_2O_3	82.26
CaO	1.96
MgO	0.45
SO_3	2.51
K_2O	0.32
Na_2O	0.07

After finishing the Arabic report and during a mission in Greece with the Economic Director, the expert received the following chemical analysis of pyrite ash from the company, Phosphoric Fertilizer Industry:

	percentage		percentage
Fe	57.0 - 58.0	P	0.3
S	1.5 - 1.8	Zn	0.04
Al	1.5 - 2.0	Pb	0.015 - 0.025
SiC_2	0.5	Sb	0.04
MgO	0.15	Ni	0.005
CaO	0.2 - 0.25	Co	0.02 - 0.25
Cu	0.28 - 0.35	$SO_{4/3}$	0.7

III. STANDARD SPECIFICATIONS FOR SRC

A. The ASTM specification for portland cement

Two types of sulphate-resisting portland cement are distinguished in the ASTM's designation C-150(1971);

(a) Type II. For general use, more especially when moderate sulphate resistance or moderate heat of hydration is desired;

(b) Type V. For use when high sulphate resistance is desired.

The standard chemical and physical requirements are shown in tables 5 and 6.

Table 5. The standard chemical requirements (ASTM)
(Percentage)

Item	Cement type	
	II and IIA	V
Silicon dioxide (SiO_2)	21.0 minimum	
Aluminium oxide (Al_2O_3)	6.0 maximum	
Magnesium oxide (MgO)	5.0 maximum	5.0 maximum
Sulphur trioxide (SO_3)		
when ($3CaO.Al_2O_3$) is 8% or less	3.0 maximum	2.3 maximum
when ($3CaO.Al_2O_3$) is more than 8%	3.5 maximum	
Loss on ignition	3.0 maximum	3.0 maximum
Insoluble residue	0.75 maximum	0.75 maximum
Tricalcium aluminate ($3CaO.Al_2O_3$)	8.0 maximum	5.0 maximum
Tetracalcium aluminoferrite plus twice the tricalcium aluminate ($4CaO.Al_2O_3$ + 2 (3CaO. Al_2O_3)) or		20.0 maximum
(C_3S + C_3A)	58.0 maximum	
Alkalies (Na_2O + 0.658 K_2O)	0.6 maximum	0.6 maximum

Table 6. The standard physical requirements (ASTM)

Item	Cement type II and IIA	Cement type V
Air content of mortar (vol. %)		
maximum	12.0	12.0
minimum	—	—
Fineness specific surface (cm^2/g)		
(alternative methods)		
turbidimeter tests		
average value, minimum	1600	1600
any one sample, minimum	1500	1500
Air permeability test		
average value, minimum	2800	2800
any one sample, minimum	2600	2600
Soundness		
autoclave expansion, (%) maximum	0.8	0.8
Strength, not less than the value shown for ages indicated below		
compressive strength (MN/m^2)		
1 day	--	--
3 days	7	--
7 days	12	10
28 days	--	21
Setting time (vicat test)		
initial set (minutes) not less than	45	45
Final set (hours) not more than	8	8

B. British standard specification for sulphate-resisting portland cement

(BS 4027:Part 2:1972)

This British Standard was produced specifically to cover sulphate-resisting portland cements. There is at present no reliable direct test for sulphate-resistance other than prolonged storage of concrete or mortar specimens in sulphate solutions and this type of test can hardly form the basis of a standard. However, experimental work and practical experience have shown that a considerable degree of sulphate-resistance is conferred on portland cement if the tricalcium aluminate is limited to 3.5%, which is the requirement of this standard. In all other respects (except for fineness), sulphate-resisting portland cement is an ordinary portland cement, and the physical requirements for it are the same as those given in BS 12 for ordinary portland cement.

Specification for the composition and manufacture of sulphate-resisting portland cement

The cement shall be manufactured by mixing together calcareous or other lime-bearing material with, if required, argillaceous and/or other silica-, alumina-, or iron-oxide-bearing materials and burning them at a clinkering temperature in conformity with the requirements of this British Standard.

No materials other than gypsum (or its derivatives) or water, or both, shall be added after burning.

Specific surface = not less than 250 m^2/kg.

Lime-saturation factor (LSF) = not more than 1.02 and not less than 0.66.

C_3A content = not more than 3.5% when calculated by the formula
$C_3A = 2.65\ (Al_2O_3) - 1.69\ (Fe_2O_3)$

Insoluble residue = not more than 1.5%.

Magnesia = not more than 4.0%.

Sulphate + hydrite SO_3 = not more than 2.5%

Loss on ignition (in temperate climates) = 3.0%
(in tropical climates) = 4.0%

Strength

Compressive strength

3 days = 8 MN/m^2
7 days = 14 MN/m^2

Setting time

Initial setting time not less than 45 minutes

Final setting time not more than 10 hours

Soundness

Expansion not more than 10 mm.

IV. RAW-MIX DESIGNS

According to ASTM specifications, there are two types of sulphate-resisting cements, Type II and Type V. The first type can be produced by increasing only the Fe_2O_3 content of the same raw mixture used in normal portland cement in LCC. This type of cement is used only to resist the action of low and moderate sulphate in soil or water.

A. Raw-mix designs for producing SRC Type II according to ASTM specification C-150

Table 7 shows the effect of increasing the Fe_2O_3 content of the same raw materials as are used in the production of normal portland cement in LCC plants, assuming the C_3S and C_3A contents to be 50% and 8% respectively.

Conclusions

From the table, the following conclusions can be drawn:

1. Sulphate-resisting cement according to ASTM specification Type II can be produced by adding a third component, rich in iron-oxide content (i.e. pyrite ash), to the same raw mix used for the normal portland cement production.

2. The limestone predominating in the Hawari quarry can be used as the main component in SRC production. The percentage of limestone used in the raw mixes varies between 57.18 and 73.66%.

3. The marl covering the Hawari limestone can be used in the range between 24.18 and 40.42%.

4. The pyrite ash used to increase the iron-oxide content of the raw mix as shown fluctuates between 1.4 and 2.4%.

5. According to the raw-mix-design calculations, the silica modulus and the alumina modulus are within the range of 1.77-2.21 and 1.21-1.37 respectively. The lime-saturation factor of the clinker produced was not less than 0.90 which indicates a high-quality cement.

Table 7. Chemical and mineralogical composition of raw mixes calculated with three components

(Calculated to 50% C_3S and 8% of C_3A) Pyrite ash = CA Mat. No. 5244 " Attisholz ".

Component		1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	12A	13A
		Raw-mix number												
Limestone designation		Z-4	Z-4	Z-5	Z-5	Z-5	Z-31	Z-31	Z-II	Z-28	Z-28	Z-31	Z-28	-II
Limestone mix. ratio (%)		64.25	70,16	71.41	65.64	61.48	62,94	58.67	57,18	62,59	64,24	60,39	73.66	56,14
Red clay designation		Z-4	Z-5	Z-5	Z-4	Z-11	Z-4	Z-11	Z-11	Z-11	Z-16	Z-16	Z-28	Z-11
Red clay mix. ratio (%)		34.34	27.85	26.63	32,96	36.70	35,44	39,28	40,42	35,27	34,07	38,07	24,18	42.23
Pyrite ash mix. ratio (%)		1.41	1,99	1,96	1,40	1,81	1.62	2,05	2,00	2.14	1,69	1,54	2,16	1.63
Calculated chemical composition of the clinker (%)	SiO_2	21.48	21.15	20.91	21.25	21,27	21.06	21.10	20.62	21,06	21.60	21,71	21,06	21,65
	Al_2O_3	5.63	6.14	6,13	5.64	5,96	5.76	6.10	6.38	6,19	5,84	5,70	6.19	5,72
	Fe_2O_3	4.10	4.90	4.88	4,11	4.62	4.30	4.83	5.27	4,97	4,42	4,21	4.97	4,23
	CaO	63.15	63.66	63.19	62.74	63.49	62,64	63.46	63.19	63,59	63,83	63,71	63,59	63,65
	MgO	2.46	2.44	2.49	2.51	2,45	3.17	3.06	3.11	2,83	2,99	3,24	2,86	3.32
	K_2O	1.04	1.08	1.04	1.01	0.98	1.06	1.03	1.00	0,97	1,00	1,05	0,97	1,00
	Na_2O	0.37	0.36	0.33	0.35	0.39	0.39	0.42	0.42	0,37	0,32	0,36	0,35	0.40
	SO_3	< 0.15	< 0.15	0.87	< 0.76	< 0.78	< 0.12	< 0.17	< 0.17	< 0,16	0,14	< 0,19	< 0,14	< 0.14
Total		98.38	99.88	99.84	98.37	99,94	98.50	100,17	100.16	100.14	100,14	100.17	100,13	100,11
Moduli	$\frac{SiO_2}{R_2O_3}$	2.21	1,91	1.90	2,17	2.01	2,09	1,93	1.77	1.89	2.10	2.19	1.88	2,18
	$\frac{Al_2O_3}{Fe_2O_3}$	1.37	1.25	1.26	1.37	1.29	1.34	1.26	1,21	1.24	1.32	1.35	1.25	1,35
Lea and Parker lime-sat. factor (%)		90.92	91.38	91.62	91.15	91.22	91.37	91.43	91.99	91.50	90.87	90,70	91.49	90.78
potential mineralogical composition of the clinker. (%)	C_3S	50.05	50.05	50.05	50.05	50.05	50.05	50.05	50.05	50.05	50.05	50.00	50.05	50.05
	C_2S	23.86	22.92	22.24	23.19	23.26	22.64	22.75	21.39	22.64	24.19	24.53	22.65	24.34
	C_3A	8.00	8.00	8.00	8,00	8.00	8.00	8.00	8,00	8.00	8,00	8.00	8.00	8.00
	C_4AF	12.46	14.90	14,82	12.50	14,04	13.06	14.68	16.03	15,12	13.45	12,80	15,11	12.87

6. The C_4AF content of the raw mix designs increases to 12.5 - 16.03% while the C_3A decreases to 8% in accordance with the stated requirement.

Accordingly, it can be stated that moderate sulphate-resisting cement complying with the ASTM specification Type II can be produced in the LCC by adding only pyrite ash within the range 1.4-2.4% to the same raw materials used in producing normal portland cement.

B. Raw-mix designs for producing SRC according to ASTM C-150 Type V and BS 4027 (1972) specifications

1. Raw-mix designs with three materials

This section of the feasibility study shows all the raw-mix designs using three materials to produce sulphate-resisting cement according to the ASTM C-150 Type V and BS 4027: 1972 specifications. These types of cement are able to resist the action of high-sulphated solutions and soil as well as seawater. In our study, we have only used the predominating local raw materials as follows:

Limestone	(Hawari quarry)
Marl	(Hawari quarry)
Gialo sand	(Ajdabiyah - Gialo road km. 90)

The ferriferous material selected to increase the iron-oxide content of the raw mix can be either

Galmoya iron ore (Sabhah area) or
Pyrite ash (imported).

Gialo sand will be introduced as a main component to increase the silica modulus.

Many trials in designing the raw mixes were made, taking into consideration changes in the lime-saturation factor (LSF) ranging from 0.88 to 0.92, accompanied by changes in the silica modulus from 2.0 to 3.0 to 3.2.

The six trial raw-mix designs with three materials were done according to the following combinations (table 8).

Table 8. Combinations of three raw materials in trial raw-mix designs

Raw mix designation	Raw materials used					Lime saturation factor	Silica modulus
	Limestone	Marl	Gialo sand	Galmoya iron ore	Pyrite ash		
A	√	-	√	√	-	0.92	3.0
B	√	-	√	√	-	0.88	3.2
C	√	√	-	√	-	0.90	2.0
D	√	-	√	√	-	0.90	2.0
E	√	√	-	-	√	0.90	2.0
F	√	-	√	-	√	0.90	2.0

The raw materials used in the three-material raw-mix designs were required to have the following chemical composition (table 9).

Table 9. Chemical components of materials in raw-mix designs (Percentage)

Components	Raw materials				
	Limestone	Marl	Gialo sand	Galmoya iron ore	Pyrite ash
S_iO_2	2.23	41.45	77.11	2.9	5.25
Al_2O_3	0.58	8.72	2.75	7.6	5.95
Fe_2O_3	0.35	4.09	1.02	78.0	82.26
CaO	51.86	19.5	8.83	--	1.96
MgO	1.48	1.7	1.40	--	0.45
SO_3	0.15	0.14	0.40	0.15	2.51
LOI	42.90	21.16	8.15	11.36	3.4

Full details of the raw-mix designs A-F, using three materials, are given in annex II.

It will be seen that limestone is considered to be the basic raw material and is used in all the designs. The other materials and the requirements for LSF and SM are varied. The following conlusions emerge from the calculations (see annex II).

Conclusions

1. It is impossible to produce sulphate-resisting cement complying with the ASTM specification C-150 Type V (1971) by using only three different raw materials as shown in the designs A-F.

2. All the values of C_3A produced in the raw-mix designs using limestone + Gialo sand + iron ore or pyrite ash (designs A,B,D) were negative (-4.7, -4.39, -9.349, -10.234 respectively), which means that a carrying alumina component must be introduced as a fourth component.

3. It is possible to produce SRC by adding iron ore or pyrite ash to the same raw materials used in producing ordinary portland cement (limestone and marl). The only drawback is that the total of $2C_3A + C_4AF$ is more than 20 (in C = 24.389, in E = 23.799) which does not comply with the ASTM specification C-150 Type V.

4. Accordingly, it is important in our case when designing any raw mix to comply with the ASTM specification Type V, to use not only the raw materials limestone, marl and Gialo sand, but to add a ferriferous fourth component, i.e. Galmoya iron ore or pyrite ash.

2. Raw-mix designs using four raw materials

This section deals with the calculations for raw mixtures using four raw materials. The calculations involved changing the following parameters:

Tricalcium silicate (C_3S), tricalcium aluminate (C_3A), silica modulus (SM), alumina modulus (AM)

The combinations of materials used and parameters required are shown in table 10.

Table 10. Trials of raw-mix designs using four raw materials

Raw-mix designation	Raw materials: Limestone	Marl	Gialo sand	Iron ore	Pyrite ash	Requirements: C_3S (%)	C_3A (%)	SM	AM
A	✓	✓	✓	✓	-	69	1.8	2.5	0.7
B	✓	✓	✓	✓	-	60	1.5	3.0	0.5
C	✓	✓	✓	✓		55	1.8	2.0	1.7
D	✓	✓	✓	-	✓	60	1.8	2.5	0.7
E	✓	✓	✓	-	✓	55	1.8	2.0	0.7

Full details of the raw-mix designs A-E are given in annex III. The results are summarized here in tables 11 and 12.

Table 11. The percentage of each raw material used and the composition of the clinker in each raw mix
(Percentage)

Raw mix	Raw materials: Limestone	Marl	Gialo sand	Iron ore	Pyrite ash	Clinker constituents: SiO_2	Al_2O_3	Fe_2O_3	CaO
A	75.4	10.2	12.9	1.4	-	24.8	2.9	3.0	65.74
B	75.8	5.5	17.8	0.9	-	27.4	2.3	2.1	64.8
C	72.2	15.5	10.3	2.04	-	24.73	3.4	4.0	64.0
D	74.3	11.4	12.9	-	1.4	25.4	2.9	3.14	64.9
E	71.9	16.3	9.9	-	1.94	24.8	3.4	4.04	63.8

Table 12. The clinker phases of each raw mix and calculation of $2C_3A + C_4AF$
(Percentage)

Raw mix	C_3S	C_2S	C_3A	C_4AF	$2C_3A + C_4AF$
A	56.229	28.645	2.331	9.105	13.767
B	37.302	50.361	2.481	6.399	11.361
C	43.855	37.83	2.274	12.148	16.696
D	47.43	37.00	2.331	9.552	14.214
E	42.4	39.1	2.268	12.279	16.815

Conclusions

1. It can be seen from the above results that four raw materials can be combined in different proportions to produce SRC according to ASTM specification C-150 Type V (1971). The proportions in which the raw materials were used are indicated in table 11. The clinker produced is characterized by the phases and constituents indicated in table 12. All the five raw-mix designs comply with the requirement of this specification that $2C_3A + C_4AF$ should not be more than 20.

2. The Galmoya iron oxide used as a fourth component in the raw-mix designs was used in the range 1.4-2.04%. This iron ore is located to the south a considerable distance from the Libyan Cement Company in Benghazi. This long distance might be the main obstacle to SRC production in the near future.

3. It is also possible to use pyrite ash instead of the Galmoya iron ore in the range 1.4-1.94%. This material can be imported from Greece, as explained before, or from any fertilizer and sulphuric-acid producing company located on any of the Mediterranean sea coasts.

4. Gialo sand will be used as a third component to increase the silica modulus of the SRC clinker produced. This material will be used in the range 9.9-17.8%.

V. ECONOMIC FEASIBILITY

As shown in the previous chapter, SRC can be produced according to ASTM specification C-150 Type V (1971), using four of the five raw materials listed. The decisive factor then would be the cost of producing this cement. A study was therefore made to compare the cost of producing SRC in the Benghazi-Hawari area with the cost of imported SRC.

A. The cost of producing SRC

The estimates of the cost of producing SRC are based on the production costs for normal portland cement in the Benghazi and Hawari Plants. Figures have been taken from the budgets of 1977, 1978 and 1979 for the Benghazi Plant and from the budget of 1979 for the Hawari Plant. Thirty per cent has been added to the highest cost shown in these budgets to compensate for the expected increase in production costs in 1980 and 1981. These figures are given in detail in annex IV. Table 13 summarizes the cost per ton of normal portland cement.

Table 13. Production costs of packed and loaded normal portland cement (Libyan dinars per ton)

Item	Cost
1. Manufacturing costs of cement (up to storage silo)	12.412
2. Packing and loading of cement	2.303
3. Sales Department expenses	0.074
4. Overhead costs	0.093
5. Administrative Department expenses[a/]	0.241
6. Financial Department expenses	0.172
7. Office expenses	0.024
8. Contracted services (experts)	0.028
9. Insurance (stores)	0.005
10. Wire and telephone services	0.010
11. Share of the company in the employee's insurance	0.408
12. Employee social benefits	0.135
13. Depreciation	0.304

14.	Travelling expenses	0.067
15.	Separation of employee from service	0.336
16.	Miscellaneous	0.040
17.	Employee benefits	0.037
18.	Various other expenses	1.011
	Total cost per ton	17.699

a/ The administrative expenses are those for the year 1978 + 50% more.

These costs can now be applied to the production of SRC, beginning with the cost of raw materials.

Raw-mix design A uses the following raw materials in these proportions:

Limestone	75.4%	Gialo sand	13.0%
Iron oxide	1.4%	Marl	10.2%

Limestone and marl costs, as shown in the costing lists (annex IV), are:

Limestone	2.658 LD per ton
Marl	1.569 LD per ton

Total cost of Gialo sand (extraction and transport to the raw-material store) 8.0 LD per ton (liable to decrease)

It was assumed that the cost of iron oxide, whether transported from the Sabhah area or imported from neighbouring countries as pyrite ash would not exceed LD 20.0 per ton. Accordingly, the cost of the raw materials used in this raw-mix design is:

Raw material	Proportion in raw mix (percentage)	Cost per ton (LD)	Cost of amount used in raw mix (LD)
Limestone	75.4	2.658	2.004
Gialo sand	13.0	8.0	1.04
Iron oxide	1.4	20.0	0.28
Marl	10.2	1.569	0.16
		Total	3.484

Raw-mix design E uses another combination of raw materials in the following proportions:

Limestone	71.88%	Gialo sand	9.87%
Pyrite ash	1.94%	Marl	16.31%

The cost of raw materials for this raw-mix design (including transport to the raw-materials store in the cement plant) is:

Raw material	Proportion in raw mix (percentage)	Cost per ton (LD)	Cost of amount used in raw mix (LD)
Limestone	71.88	2.658	1.910
Gialo sand	9.87	8.00	0.79
Pyrite ash	1.94	20.00	0.39
Marl	16.31	1.569	0.25
		Total	3.340

It will be seen that the raw-material cost of raw-mix design E is less than the raw-material cost of raw-mix design A by about 0.144 LD per ton. To be on the safe side, we will use the higher cost in the following calculation.

Costing list for SRC	LD per ton
Cost of raw materials (loss on ignition factor = 1.556) + 10% losses	6.000
Grinding of raw materials (LOI factor = 1.556) + 10%[a/]	2.065
Cost of burning raw materials in rotary kilns + 10%[b/]	5.770
Cost of clinker storage	0.190
	14.347
Cost of clinker (93%)	13.343
Cost of gypsum (7%)	0.454
	13.797

Cost of cement grinding + 10%[c/]	1.910
Cost of cement storage	0.195
Cost of cement packing (delivered on board trucks)	2.303
Overhead costs	3.000
Total cost of SRC per ton	21.205

a/ 10% was added to the cost of grinding raw materials due to the difficulty of grinding sand as one of the raw-mix components. There is also the high consumption rate of the grinding media and the lining plates in comparison with grinding the raw materials used in normal portland cement.

b/ 10% was added to the cost of burning the raw materials used in sulphate-resisting raw mix as the burning of these raw materials requires more fuel, besides a higher consumption of lining bricks in comparison with the consumption when burning normal portland cement.

c/ 10% was added to the cement-grinding costs as the silica modulus of sulphate-resisting cement is more than the silica modulus in normal portland cement. This higher silica modulus makes it harder to grind the SRC clinker and this, in turn, means more wear on the grinding media and lining plates than in grinding normal portland cement clinker.

B. The cost of imported SRC

The Libyan Cement Company imports SRC which complies with the British Standard Specification on a tender basis. As it is necessary to compare the average cost of the imported SRC with the expected cost of SRC production as shown in section A, the costs for three different shipments of imported SRC, discharged in three different ports, were taken at random.

The imported cement shipments chosen were the eighth shipment to Misratah, the thirteenth shipment to Derna and the seventeenth shipment to Benghazi.

The contracted prices were:

	Dollars per ton
To the eastern ports, Benghazi and Derna	69.00
To the western ports, Tripoli and Misratah	70.00

Table 14 shows the cost of these shipments.

These shipments taken together give an average cost:

	LD per ton
Shipment 8 to Misratah	30.250
Shipment 13 to Derna	27.554
Shipment 17 to Benghazi	35.876
Total	93.680

Mean cost of one ton of imported SRC (delivered to the cement store)	31.227
Estimated cost of producing one ton of SRC at LCC	21.205
Cost difference	10.022

Conclusion

According to this study, the production of sulphate-resisting cement at LCC will achieve an average saving of about LD 10.0 per ton.

Table 14. Cost of imported sulphate-resisting cement
(Libyan dinars)

Item	Shipment number and harbour		
	Shipment 8 Misratah	Shipment 13 Derna	Shipment 17 Benghazi
Local bank charges	75 313.0	17 460.7	22 865.0
Commission agent (0.4% of the price+freight+demurrage)	378.1	72.1	113.0
Local insurance (LD 0.14 per ton)	501.2	117.6	154.0
Demurrage (55 cents per ton per day)	19 205.5	575.9	5 386.7
Freight expenses (according to contract 4% of freight)			4 120.4

Transport costs		152.6	195.9
Shipping agent's charge (LD 0.9 per ton)			990.9
Subtotal	95 397.8	18 378.9	33 825.9
LCC administration expenses (8%)	7 631.8	1 470.3	2 706.1
Taxes (2.2%)	2 266.7	297.8	732.1
Total	105 296.3	20 247.0	37 264.1
Cost per ton			
All costs as shown above	27.4	24.1	33.9
Expenses (2% per ton)	00.9	00.6	-
Transport costs	2.0	2.0	2.0
Shipping agent's charge	-	0.9	-
Total (delivered to store)	30.3	27.6	35.9
		(Tons)	
Quantity co[illegible]ted	3 850	840	1 100

VI. SELECTION OF METHOD AND MOST SUITABLE PRODUCTION LINE

In order to explain the processes used in producing normal portland cement in the LCC plants, explanatory drawings of the production processes in Benghazi and Hawari and flow charts of production lines I, II and III in the Benghazi Cement Plant have been given in annex V. These show all the processes from raw-material crushing, grinding and burning, through to cement dispatching in bulk or in paper bags.

From these explanatory drawings, the following conclusions can be drawn.

Conclusions

1. SRC can be produced in any LCC production line, either in Hawari or in Benghazi. The same equipment and machinery can be used with only minor changes in handling materials as follows:

(a) The iron-oxide ore or pyrite ash has to be mixed with limestone in the required percentage at the crushing department or after entering the raw-material store;

(b) Sand can be added to the raw materials in the raw-mill additive hoppers according to the percentage required for the raw-mix design;

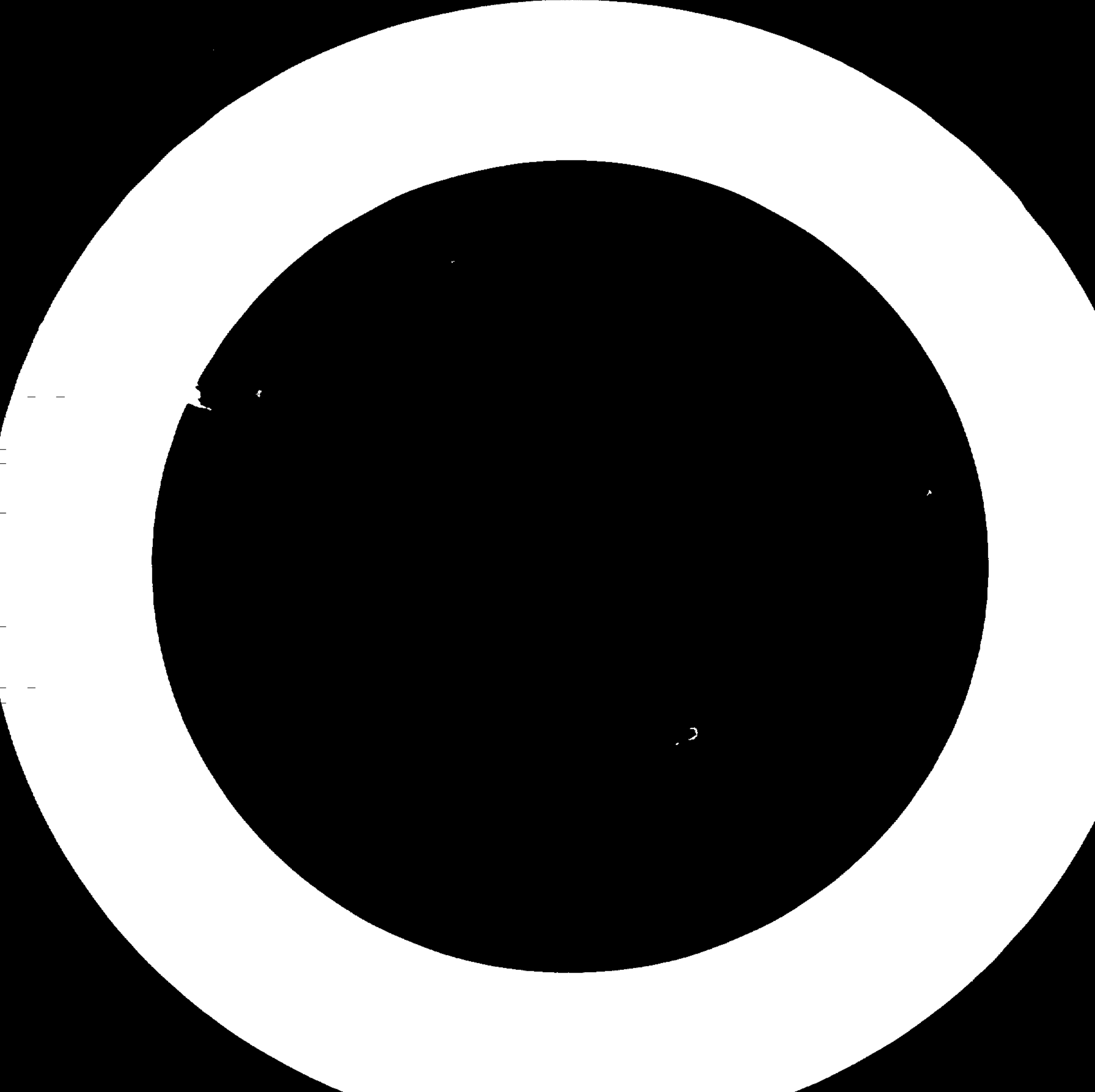
(c) If SRC according to ASTM Type II is produced, it would be preferable to introduce iron-oxide ore or pyrite ash to the raw materials in the raw mills through the additive hopper.

2. If there is a large demand for SRC in the Libyan Arab Jamahiriya and it is desired to avoid all imports of this type of cement, it would be possible to devote a whole cement plant, either Hawari or Benghazi, to SCR production. It would be necessary to stock the raw-materials stores with sufficient sand and iron ore or pyrite ash for the volume of SRC production required.

3. If one of the LCC plants (Hawari or Benghazi) is devoted to the production of SRC, then the clinker stores ought also to be completely or partly reserved for storage of the SRC clinker produced, since the mixing of two types of clinker ought to be completely avoided. It is also recommended that SRC production should continue only for part of the year.

4. If the quantity of SRC required is not so great, then it would be preferable to set aside the first or second production line at the Benghazi Cement Plant, or both the two production lines, to produce this type of cement.

5. If the first or second production line at the Benghazi Cement Plant is reserved for SRC production, then the clinker silos I or II can be used to store SRC clinker in order to completely separate the two types of cement produced in the Benghazi Cement Plant.



Annex I

AVERAGE COMPOSITION OF REPRESENTATIVE SAMPLES OF LIMESTONE AND MARL FROM BORINGS IN THE HAWARI-BENGHAZI AREA
(Percentage)

Component	Boring CH-1 Depth (m)				Boring CH-2 Depth (m)			
	0 - 1	1-6.5	6.5-25.5	25.5-44	0 -2	2 - 6.5	6.5 -23	23- 40
SiO_2	39.15	41.78	0.73	0.49	29.14	43.07	0.58	0.25
TiO_2	0.39	0.49	trace	trace	0.26	0.45	trace	trace
Al_2O_3	8.03	9.36	0.25	0.17	5.95	8.33	0.21	0.10
Fe_2O_3	3.83	4.41	0.35	0.22	3.00	3.90	0.63	0.07
CaO	21.08	18.51	52.06	52.36	28.28	19.97	49.50	51.97
MgO	1.84	1.77	2.19	2.53	1.90	1.71	3.27	2.64
K_2O	2.24	2.34	0.08	0.07	1.72	2.10	0.07	0.04
Na_2O	0.22	0.27	0.06	0.06	0.26	0.45	0.09	0.09
SO_3	0.16	0.16	0.93	0.63	0.21	0.17	1.91	0.36
Cl	0.008	0.018	0.012	0.015	0.028	0.031	0.038	0.071
Loss on ignition	22.71	20.61			27.38	20.42		

Component	Boring CH-3 Depth (m)				Boring CH-4 Depth (m)			
	0 – 2	2– 6.5	6.5–23	23–49	0–1	2– 5	5–26	26 – 49
SiO_2	34.62	51.95	0.74	0.34	23.70	31.92	1.12	0.28
TiO_2	0.34	0.72	trace	trace	0.18	0.33	trace	trace
Al_2O_3	7.21	11.44	0.27	0.13	4.58	7.32	0.32	0.12
Fe_2O_3	3.56	5.24	0.12	0.24	2.35	3.51	0.15	0.76
CaO	24.02	10.63	52.51	51.72	33.34	26.54	52.63	50.42
MgO	1.02	1.72	2.38	2.39	1.72	1.60	2.00	2.48
K_2O	1.96	2.43	0.07	0.05	1.44	1.78	0.11	0.04
Na_2O	0.33	0.63	0.09	0.08	0.20	0.30	0.05	0.08
SO_3	0.18	0.13	0.37	0.86	0.35	0.22	0.31	2.00
Cl	0.026	0.025	0.032	0.040	0.027	0.023	0.013	0.052
Loss on ignition	24.59	15.12			30.69	25.43		

Component	Boring CH-5 Depth (m)				Boring CH-6 Depth (m)			
	0 - 1	1 - 5 7	5 7 - 21	21 - 40	0 - 1	1 - 6	6 - 23	23 - 40
SiO_2	32.72	42.99	0.66	0.38	25.33	40.18	0.48	0.57
TiO_2	0.31	0.50	trace	trace	0.20	0.40	trace	trace
Al_2O_3	6.78	9.25	0.21	0.14	4.80	7.57	0.16	0.17
Fe_2O_3	3.41	4.38	0.08	0.06	2.56	3.69	0.06	0.33
CaO	25.13	18.29	52.88	52.15	32.34	22.55	53.19	50.63
MgO	1.83	1.68	2.20	2.67	1.84	1.52	1.95	2.68
K_2O	1.89	2.22	0.07	0.05	1.51	1.99	0.06	0.07
Na_2O	0.19	0.35	0.05	0.06	0.17	0.36	0.06	0.10
SO_3	0.13	0.15	0.21	0.26	0.20	0.13	0.28	0.95
Cl	0.007	0.21	0.013	0.022	0.013	0.008	0.024	0.102
Loss on ignition	25.61	20.14			31.06	22.14		

Component	Boring CH-7 Depth (m)				Boring CH-8 Depth (m)			
	0 - 1	1 - 5.65	5.5 - 23	23 - 40	0 - 1	2 - 5.9	5.9 - 23	23 - 40
SiO_2	17.72	33.21	0.50	0.54	37.78	48.97	0.54	0.25
TiO_2	0.11	0.32	trace	trace	0.39	0.71	trace	trace
Al_2O_3	3.34	7.02	0.17	0.18	7.78	11.78	0.19	0.10
Fe_2O_3	1.73	3.40	0.05	0.10	3.80	5.53	0.27	0.36
CaO	40.22	26.65	53.47	51.57	22.57	11.92	51.13	51.32
MgO	1.74	1.55	1.72	2.93	1.82	1.70	2.85	2.43
K_2O	1.07	1.56	0.07	0.07	2.04	2.52	0.07	0.04
Na_2O	0.14	0.24	0.05	0.07	0.28	0.45	0.05	0.08
SO_3	0.34	0.20	0.36	0.29	0.11	0.07	0.85	1.28
Cl	0.007	0.005	0.017	0.042	0.011	0.014	0.014	0.044
Loss on ignition	33.58	25.85			23.33	16.34		

Component	Borings CH-9 and CH-10 Depth (m)					Borings CH-11, CH-12 and CH-13 Depth (m)					
	0-1	1-4	4.9-6.6	0-1	1-6	0-1	1-6.4	0-1	1-5.5	0-1	1-5
SiO_2	25.31	55.17	37.49	21.95	61.22	35.39	46.19	30.49	44.62	48.88	46.11
TiO_2	0.20	0.90	0.34	0.17	0.79	0.34	0.55	0.27	0.59	0.59	0.60
Al_2O_3	5.07	13.12	6.69	4.64	11.00	7.26	9.31	6.27	10.64	10.03	10.67
Fe_2O_3	2.58	5.19	3.10	2.30	4.53	3.50	4.36	3.15	5.11	4.58	4.99
CaO	32.03	6.87	25.12	34.93	7.57	24.16	16.50	28.22	15.22	13.16	14.73
MgO	1.99	1.58	1.40	1.70	1.50	1.86	1.67	1.69	1.64	1.79	1.73
K_2O	1.42	2.61	1.89	1.38	2.21	2.03	2.[illegible]1	1.89	2.41	2.59	2.37
Na_2O	0.21	0.53	0.33	0.18	0.50	0.23	0.46	0.19	0.47	0.31	0.51
SO_3	0.19	0.03	0.26	0.35	0.03	0.18	0.12	0.14	0.09	0.11	0.12
Cl	0.023	0.012	0.020	0.019	0.005	0.011	0.03	0.008	0.018	0.018	0.125
Loss on ignition	30.13	12.94	23.49	32.37	10.68	25.08	18.59	27.68	19.19	16.90	18.00

Component	Borings CH-14 and CH-16 Depth (m)				Boring CH-15 Depth (m)			
	0 - 1	1 - 5.5	0 - 1	1 - 4.3	0 - 1	1 - 4	6 - 18	18 - 30
SiO_2	46.31	41.43	27.07	54.13	27.85	41.53	0.31	0.49
TiO_2	0.52	0.43	0.22	0.85	0.23	0.46	trace	trace
Al_2O_3	9,78	8.32	5.30	12.70	5.60	8.54	0.12	0.19
Fe_2O_3	4.47	4,02	2.67	5.94	2.80	4.09	0.04	0.21
CaO	15,88	20.15	30.47	8.05	30.43	20.12	53.72	50.97
MgO	1.63	1.75	1.99	1.65	1.87	1.81	2.07	3.26
K_2O	2,37	2.06	1.59	2.54	1.58	2.02	0.04	0.06
Na_2O	0,26	0.34	0.19	0.54	0.16	0.31	0.05	0.08
SO_3	0.14	0,08	0.24	0.06	0.19	0.07	0.25	0.61
Cl	0.005	0.014	0.012	0.017	0.009	0.008	0.014	0.024
Loss on ignition	18.59	21.11	29.08	13.54	28.92	21.03		

Component	Boring CH-17 Depth (m)			
	0 - 1	1 - 5	5 - 22	22 - 40
SiO_2	29.21	42.96	3.22	0.67
TiO_2	0.25	0.51	0.01	trace
Al_2O_3	5.75	9.46	0.76	0.24
Fe_2O_3	2.93	4.45	0.34	0.32
CaO	29.73	18.47	51.77	52.58
MgO	1.81	1.49	1.12	1.63
K_2O	1.79	2.10	0.26	0.09
Na_2O	0.17	0.42	0.11	0.11
SO_3	0.17	0.07	0.18	0.71
Cl	0.013	0.022	0.061	0.114
Loss on ignition	20.17	20.08		

Annex II

RAW-MIX DESIGNS A-F USING THREE RAW MATERIALS

Abbreviations

A = alumina

C = calcium oxide

F = iron oxide

S = silica

LSF = lime-saturation factor

SM = silica modulus

LOI = loss on ignition

RAW-MIX DESIGN A

The following raw materials will be applied in our raw mix according to the following requirements:

a - Limestone LSF = 0.92

b - Gialo sand

c - Iron Ore SM = 3

$$C_{(max)} = 2.8\ S + 1.18\ A + 0.65\ F$$

$$C_{(max)_a} = 2.8 \times 2.23 + 1.18 \times 0.58 + 0.65 \times 0.35 = 7.156$$

$$C_{(max)_b} = 2.8 \times 77.11 + 1.18 \times 2.75 + 0.65 \times 1.02 = 219.816$$

$$C_{(max)_c} = 2.8 \times 2.9 + 1.18 \times 7.6 + 0.65 \times 78.0 = + 67.788$$

$$\Delta\ LSF = C - [LSF\ (required) \times C_{(max)}]$$

$$\Delta\ LSF\ a = 51.86 - (0.92 \times 7.156) = 45.277$$

$$\Delta\ LSF\ b = 8.83 - (0.92 \times 219.82) = -193.404$$

$$\Delta\ LSF\ c = 0.00 - (0.92 \times 67.788) = -62.365$$

$$\Delta\ SM = S - [SM\ (required) \times (A+F)]$$

$\Delta SM_a = 2.23 - [\,3 \times (0.58 + 0.35)\,] = -0.56$

$\Delta SM_b = 77.11 - [\,3 \times (2.75 + 1.02)\,] = 65.8$

$\Delta SM_c = 2.9 - [\,3 \times (7.6 + 78.00)\,] = -253.9$

Δ LSF	$(\Delta LSF)_a$	$(\Delta LSF)_b$	$(\Delta LSF)_c$	
Δ SM	$(\Delta SM)_a$	$(\Delta SM)_b$	$(\Delta SM)_c$	
	X_a	X_b	X_c	Σ
	(a)	(b)	(c)	
ΔLSF	45.277	-193.404	-62.365	
Δ SM	-0.56	65.8	-253.9	
	53215.129	11530.755	2870.92	67616.804
	53215.129x100	11530.755x100	2870.92x100	
	67616.804	67616.804	67616.804	
%	78.701	17.053	4.246	

a = [−193.404 x (− 253.9)] − [−62.365 x 65.8] = 53215.129

b = [45.277 x (− 253.9)] − [−62.365 x (− 0.56)] = 11530.755

c = (45.277 x 65.8) − [(− 193.404) x (−0.56)] = 2870.92

Total a+b+c = 5321.129 + 11530.755 + 2870.92 = 67616.804

% of raw materials components a, b, c,

% Limestone = $\frac{53215.129 \times 100}{67616.804}$ = 78.701

% Sand = $\frac{11530.755 \times 100}{67616.804}$ = 17.053

% Iron ore = $\frac{2870.92 \times 100}{67616.804}$ = 4.246

Raw-mix components

$$SiO_2\% = \frac{78.701 \times 2.23}{100} + \frac{17.053 \times 77.11}{100} + \frac{4.246 \times 2.9}{100}$$

$$= 1.755 + 13.150 + 0.123 = 15.028.$$

$$Al_2O_3\% = 0.78701 \times 0.58 + 0.17053 \times 2.75 + 0.04246 \times 7.6$$

$$= 0.456 + 0.469 + 0.323 = 1.248$$

$$FeO\% = 0.78701 \times 0.35 + 0.17053 \times 1.02 + 0.04246 \times 78.0$$

$$= 0.275 + 0.174 + 3.312 = 3.761$$

$$CaO\% = 0.78701 \times 51.86 + 0.17053 \times 8.83 + 0.04246 \times 0.0$$

$$= 40.814 + 1.506 + 0.0 = 42.320$$

$$LOI\% = 0.78701 \times 42.90 + 0.17053 \times 8.15 + 0.04246 \times 11.36$$

$$= 33.763 + 1.390 + 0.482 = 35.630$$

$$F^{-1} = 1 - 0.01 \times LOI$$

$$= 1 - 0.01 \times 35.635$$

$$= 1 - 0.35635 = 0.64365.$$

$$F = \frac{1}{0.64365} = 1.554.$$

Clinker compositich

$$SiO_2\% = 15.028 \times 1.554 = 23.354$$

$$Al_2O_3\% = 1.248 \times 1.554 = 1.939$$

$$Fe_2O_3\% = 3.761 \times 1.554 = 5.845$$

$$CaO\% = 42.320 \times 1.554 = 65.765$$

Clinker phases

$C_3S = 4.071\ CaO - 7.6\ SiO_2 - 6.718\ Al_2O_3 - 1.43\ Fe_2O_3$

$C_2S = 8.602\ SiO_2 + 5.068\ Al_2O_3 + 1.078\ Fe_2O_3 - 3.071\ CaO$

$= 2.867\ SiO_2 - 0.7544\ C_3S$

$C_4AF = 3.043\ Fe_2O_3$

$C_3A = 2.65\ Al_2O_3 - 1.692\ Fe_2O_3$

From the clinker composition

$C_3S = 68.855$
$C_2S = 15.013$
$C_3A = -4.752$
$C_4AF = 17.786$

As shown, C_3A is negative which means that the raw mix is in need of Al_2O_3 which can be supplied by the introduction of clayey materials (marl). Another trial, changing our requirements, can be applied before introducing the clayey materials as follows:

RAW-MIX DESIGN B

The same raw materials used in raw-mix design A will be applied according to the following requirements:

LSF = 0.88

SM = 3.2

$C_{(max)_a} = 7.156 = C_{(max)_b} = 219.816$

$C_{(max)_c} = 67.789$

$LSF_a = 45.563$

SM_a = − 0.746

SM_b = 65. 046

SM_c = − 271.02

	a	b	c	Σ
LSF	45.563	−184.608	−59.553	
SM	−0.746	65.046	−271.02	
	53912.649	123921.985	2825.973	69131.607
	53912.649x100	123921.985x100	2825.973x100	
	69131.607	69131.607	69131.607	
%	77.985	17.927	4.088	

Raw-mix components

SiO_2 % = 15.681 Al_2O_3 % = 1.256

Fe_2O_3 % = 3.644 CaO % = 42.026

LOI % = 35.381

$$F = (1-0.35381)^{-1}$$
$$= (0.64619)^{-1}$$
$$= \frac{1}{0.64619} = 1.548$$

Clinker composition

SiO_2 = 24.274 Al_2O_3 % = 1.944

Fe_2O_3 % = 5.[illegible] CaO % = 65.056

Clinker phases

C_3S = 59.234 C_2S = 24.907

C_3A = −4.393 C_4AF = 17.166

N.B. C_3A is negative.

RAW-MIX DESIGN C

The following raw materials were applied in raw-mix design C according to the requirements:

a - Limestone b - Marl c - Iron Ore.

LSF = 0.9

SM = 2.0

$C_{(max)_a}$ = 7.156 $C_{(max)_b}$ = 129.000

$C_{(max)_b}$ = 67.788

LSF_a = 45.420

LSF_b = -96.607

LSF_c = -61.009

SM_a = 0.37

SM_b = 15.83

SM_c = -168.3

	a	b	c	
Δ LSF	45.420	- 96.607	- 61.009	
Δ SM	0.37	15.83	-168.3	
	17224.731	- 7621.613	754.743	25601.087
	17224.731x100	7621.613x100	754.743x100	
	25601.087	25601.087	25601.087	
%	67.281	29.771	1.948	

Raw-mix components

SiO_2 % = 13.926 Al_2O_3 % = 3.210

Fe_2O_3 % = 3.753 CaO % = 40.697

LOI % = 34.498

F = 1.550

Clinker composition

SiO_2 %	= 21.585	Al_2O_3 %	= ..976
Fe_2O_3 %	= 5.[illegible]17	CaO %	= 63.080

Clinker phases

C_3S	= 51.006	C_2S	= 23.405
C_3A	= 3.3[illegible]4	C_4AF	= 17.701

N.B. 2 C_3A + C_4AF is more than 20

RAW-MIX DESIGN D

The following raw materials were applied in raw-mix design D according to the requirements:

a - Limestone b - Gialo sand c - Iron ore

LSF = 0.9

SM = 0.2

$C_{(max)_a}$ = 7.156 $C_{(max)_b}$ = 219.816

$C_{(max)_c}$ = 67.788

LSF_a = 45.42

LSF_a = -189.004

LSF_c = -61.009

SM_a = 0.37

SM_b = 69.57

SM_c = -138.3

	a	b	c	
a LSF	45.420	-189.004	-61.009	
a SM	0.37	69.57	-168.3	
	36053.769	-7621.613	3229.301	46905.183
	36053.769x100	7621.613x100	3229.801x100	
	46905.183	46905.183	46905.183	
%	76.865	16.249	6.886	

Raw-mix components

SiO_2 % = 14.443 Al_2O_3 % = 1.416

Fe_2O_3 % = 5.806 CaO % = 41.297

LOI % = 35.082

F = 1.540

Clinker composition

SiO_2 % = 22.242 Al_2O_3 % = 2.181

Fe_2O_3 % = 3.941 CaO % = 63.597

Clinker phases

C_3S = 62.427 C_2S = 16.673

C_3A = -9.349 C_4AF = 27.207

N.B. 2 C_3A + C_4AF = more than 20

RAW-MIX DESIGN E

The following raw materials were applied in raw mix-design E according to the requirements:

a - Limestone b - Marl c - Pyrite ash

LSF = 0.9

SM = 2.0

$C_{(max)_a}$ = 7.156

$C_{(max)_b}$ = 129.000

$C_{(max)_c}$ = 75.19

LSF_a = 25.42

LSF_b = -96.607

LSF_c = -65.711

SM_a = 0.37

SM_b = 15.83

SM_c = 171.17

	a	b	c	
Δ LSF	45.420	- 96.607	- 65.711	
Δ SM	0.37	15.83	-171.17	
	17576.425	- 7750.228	754.743	26081.396
	17576.425x100 / 26081.396	7750.208x100 / 2608 .396	754.743x100 / 26081.396	
%	67.390	29.716	2.894	

<u>Raw-mix components</u>

SiO_2 % = 13.972 Al_2O_3 % = 3.154

Fe_2O_3 % = 3.832 CaO % = 40.780

LOI % = 35.297

F = 1.545

<u>Clinker composition</u>

SiO_2 % = 21.587 Al_2O_3 % = 4.873

Fe_2O_3 % = 5.920 CaO % = 63.005

<u>Clinker phases</u>

C_3S = 51.230 C_2S = 23.[illegible]

C_3A = 2.892 C_4AF = 18.015

N.B. $2C_3A$ + C_4AF is more than 20

RAW-MIX DESIGN F

The raw materials applied in our raw-mix design F are:

a - Limestone b - Gialo sand c - Pyrite ash

Our requirements are:

LSF = 0.9

SM = 2.0

$C_{(Max)_a}$ = 75.19 $C_{(Max)_b}$ = 219.316

$C_{(Max)_c}$ = 75.19

$L.S.F_a$ = 54.[illegible]20

$L.S.F_b$ = -189.304

$L.S.F_c$ = -65.711

SM_a = 0.37

SM_b = 69.57

SM_c = -171.17

	a	b	c	
L.S.F	45.420	- 189.304	- 65.711	
SM	0.37	69.57	- 171.17	
	36923.329	- 7750.228	3229.801	47903.358
	36923.329x100 / 47903.358	7750.228x100 / 47903.358	3229.801x100 / 47903.358	
	77.079	16.179	6.742	

Raw-mix composition

SiO_2 % = 14.548

Fe_2O_3 % = 5.981

LOI % = 34.615

Al_2O_3 % = 1.293

CaO % = 41.534

$$F = \left[1 - (0.01 \times 34.610)\right]^{-1} = (0.65385)^{-1}$$

$$= \frac{1}{0.65385} = 1.529$$

Clinker composition

SiO_2 % = 22.244

Fe_2O_3 % = 9.145

Al_2O_3 % = 1.977

CaO % = 63.505

Clinker phases

C_3S = 63.116

C_3A = -10.234

C_2S = 16.159

C_4AF = 27.828

Annex III

RAW-MIX DESIGNS A-E USING FOUR COMPONENTS

Abbreviations

A = alumina LOI = loss on ignition

C = calcium oxide SM = silica modulus

F = iron oxide AM = alumina modulus

S = silica

RAW-MIX DESIGN A

The applied raw materials in raw-mix design A are:

a - Limestone b - Marl

c - Gialo sand d - Iron ore

Our requirements are:

$C_3S = 69$ $C_3A = 1.8$

SM = 2.9 AM = 0.7

F (factor) = 1-0.01 LOI

$\Delta C_3S = 4.07\,C - 7.6\,S - 6.72A - 1.43F - (C_3S \text{ required}) \times F \text{ (factor)}$

$\Delta C_3A = 2.65A - 1.69F - C_3A(\text{required}) \times F \text{ (factor)}$

$F_{(a)} = 1 - (0.01 \times 42.9) = 0.571$

$F_{(b)} = 1 - (0.01 \times 8.15) = 0.919$

$F_{(c)} = 1 - (0.01 \times 11.36) = 0.886$

$F_{(d)} = 1 - (0.01 \times 21.16) = 0.788$

$C_3S_a = (4.07 \times 51.86) - (7.6 \times 2.23) - (6.72 \times 0.58) - (1.43 \times 0.35) - (.571 \times 69) = 150.325$

$C_3S_b = (4.07 \times [illegible].03) - (7.6 \times 77.11) - (6.72 - 2.75) - (1.43 \times 1.0[illegible]) - (0.919 \times 69.0) = -633.440$

$C_3S_c = (4.07 \times 0.0) - (7.6 \times 2.9) - (6.27 \times 7.6) - (1.43 \times 78) - (0.886 \times 69.0) = -245.786$

$C_3S_d = (4.07 \times 19.5) - (7.6 \times 41,45) - (6.72 \times 8.72) - (1.43 \times 4.09) - (0.788 \times 69.0) = -354.474$

$C_3A_a = (2.65 \times 0.58) - (1.69 \times 0.35) - (0.571 \times 1.8) = -0.0823$

$C_3A_b = (2.65 \times 2.75) - (1.69 \times 1.09) - (0.919 \times 1.8) = 3.910$

$C_3A_c = (2.65 \times 7.6) - (1.69 \times 78.0) - (0.886 \times 1.8) = -113.275$

$C_3A_d = (2.65 \times 0.72) - (1.69 \times 4.09) - (0.788 \times 1.8) = 14.778$

$a_1 = b \times c$ $b_1 = a \times c$ $c_1 = a \times b$

$a_2 = b \times d$ $b_2 = a \times d$ $d_2 = a \times b$

$a_3 = c \times d$ $c_3 = a \times d$ $d_3 = a \times c$

	a	b	c	d	Total
ΔC_3S	150. 325	- 633.448	- 245.756	- 354.474	
ΔC_3A	-0.0823	3.910	- 113.275	14.778	
1	- 72714.845	- 17048.293	535.638	—	90298.776
2	- 7975.101	2192.330	---	535.638	10703.069
3	- 43785.268	---	2129.330	-17048.293	63025.891
1	72714.85x100 / 90298.776	17048.293x100 / 90298.776	535.638x100 / 90298.776	....	.....
2	7975.101x100 / 10703.069	2192.33x100 / 10703.069	. . / . .	535.638x100 / 10703.069	
3	43785.268x100 / 63025.891	. . . /	2192.33x100 / 63025.891	17048.293x100 / 63025.891	
% 1	80527	18.880	0.593	.....	
% 2	74.512	20.483	...	5..005	
% 3	[illegible].472	.....	3.478	27.05	

Composition	1 (a+b+c)	2 (a +b+ d)	3 (a+c +d)
SiO_2(1)	16.371	19.531	12.862
Al_2O_3	1.031	1.432	3.026
Fe_2O_3	0.937	0.674	4.062
$Al_2O_3 + Fe_2O_3$	1.968	2.106	7.088

SiO_2 (1) = (2.23 x 0.80527) + (77.11 x 0.1888)
+ (2.9 x 0.00593) = 16.371

SiO_2 (2) = (2.23 x 0.74512) + (77.11 x 0.20483)
+ (41.45 x 0.5005) = 19.53

SiO_2 (3) = (2.23 x 0. 69472) + (2.9 x 0.03478)
+ (41.45 x 0.2705) = 12.862

Al_2O_3(1) = (0.58 x 0. 80527) +(2.75 x 0. 1888)
+ (7.6 x 0. 00593) = 1.031

AlO_3(2) = (0.58 x 0.74512) + (2.75 x 0.20483)
+ (8.72 x 0.5005) = 1.432

Al_2O_3(3) = (0.58 x 0. 69472) + (7.6x 0.03478)
+ (8.72 x 0.2705) = 3.026

Fe_2O_3(1) = (0.35x0.80527) + (1.02x 0.1888)
+ (78.0 x 0.00593) = 0.937

Fe_2O_3(2) = (0.35 x 0.74512) + (1.02 x 0.20483) +
+ (4.09 x 0. 5005) = 0.674

Fe_2O_3(3) = (0.35x 0.69472) + (78.0x0.03478) +
+ (4.09 x 0.2705) = 4.062

$$SM = SiO_2 \left[SM (Al_2O_3 + Fe_2 O_3) \right]$$

SM (1) = 16.371 - (2.5 x 1.968) = 11.451

SM (2) = 19.531 - (2.5 x 2.106) = 14.266

SM (3) = 12.862 - (2.5 x 7.088) =-4.858

AM = $Al_2 O_3$ - (AM x $Fe_2 O_3$)

AM (1) = 1.031 - (0.7 x 0.937) = 0.375

AM (2) = 1.432 - (0.7 x 0.674) = 0.96

AM (3) = 3.026 - (0.7 x 4.062) = 0.183

	1	2	3	
♠ SM	11.452	14.266	4.858	
♠ AM	0.375	0.96	0.183	
	7.274	3.917	5.643	16.834
	7.274x100	3.917x100	5.643x100	
	16.834	16.834	16.834	
	43.210	23.268	33.522	

(1) = (2x3) = (14.266x0.183) - (0.960x - 4.858) = 7.274

(2) = (1x3) = 3.917

(3) = (1x2) = 5.643

a = (43.21 x 0 60527) + (23.268 x 0.74512) + (33.522 x 0.68472)
= 75.422

b = (43.21 x 0.1888) + (23 x 0.268 x 0.20483) = 12.924

c = (43.21 x 0.00593) + (33.522 x 0.03478) = 1.422

d = (23.268 x 0.5005) + (33.522x0.2405)= 10.232

Raw-mix composition

$$SiO_2 \% = \frac{2.23 \times 75.422}{100} + \frac{77.11.12.924}{100} + \frac{2.9 \times 1.422}{100} + \frac{41.45 \times 10.232}{100} = 15.93$$

Al_2O_3 % = 0.58 x 0.75422 + 2.75 x0.12924 + 7.6 x 0.01422 +8,72 x 0.10230.12
= 1.793

Fe_2O_3 % = (0.35 x 0.75422) + (1.02 x 0.12924) + (0.78 x 0.01422)
+ (4.09 x 0.10232) = 1.923

$CaO\ \% = (51.86 \times 0.75422) + (8.63 \times 0.12923) + (0.0 \times 0.01422) + (19.5 \times 0.10232) = 42.25$

$LOI = (42.9 \times 0.75422) + (0.15 \times 0.12923) + (11.36 \times 0.01422) + (21.16 \times 0.10232) = 35.736$

$F(\text{factor}) = 1 - (0.01 \times LOI) = 1 - (0.01 \times 35\ 35.736) = 0.64264$

$$\text{Factor} = \frac{1}{0.64264} = 1.556$$

Clinker composition

$SiO_2\ \% = 15.93 \times 1.556 = 24.787$

$Al_2O_3\ \% = 1.793 \times 1.556 = 2.790$

$Fe_2O_3\ \% = 1.923 \times 1.556 = 2.992$

$CaO\ \% = 42.25 \times 1.556 = 65.741$

Clinker phases

$C_3S = (4.071 \times 65.74) - (7.6 \times 24.787) - (6.718 \times 2.76) - (1.43 \times 2.992) = 56.229$

$C_2S = (2.867 \times 24.787) - (0.7544 \times 56.229) = 28.645$

$C_3A = (2.65 \times 2.79) - (1.692 \times 2.992) = 2.331$

$C_4AF = 3.043 \times 2.992 = 9.105$

$2\ C_3A + C_4AF$ = 13.767 (less than 20 and complies with the ASTM Specification, type V)

RAW-MIX DESIGN B

In our raw-mix design B, the following four raw materials were applied with the given requirements:

a - Limestone b - Marl c - Gialo sand d - Iron oxide

Requirements

$C_3S = 60$ $C_3A = 1.5$

$SM = 3$ $AM = 0.5$

$F_a = 0.571$ $F_b = 0.919$

$F_c = 0.886$ $F_d = 0.788$

$C_3S_a = 155.464$ $C_3S_b = -625.177$

$C_3S_c = -237.812$ $C_3S_d = -347.382$

$C_3A_a = 0.089$ $C_3A_b = 4.185$

$C_3A_c = 113.009$ $C_3A_d = 15.014$

	a	b	c	d	
ΔC_3S	155.464	-625.177	-237.812	-347.382	Total
ΔC_3A	0.089	4.185	-113.009	15.014	
1	71645.871	17547.666	706.258	—	89899.795
2	-7932.614	2365.053	—	706.258	11003.925
3	-42827.802	—	2365.053	-17547.677	62740.521
1	$\frac{71645.871 \times 100}{89899.795}$	$\frac{17547.666 \times 100}{89899.795}$	$\frac{706.258 \times 100}{89899.795}$	—	
2	$\frac{7932.614 \times 100}{11003.925}$	$\frac{2365.053 \times 100}{11003.925}$	—	$\frac{706.256 \times 100}{11003.925}$	
3	$\frac{42827.802 \times 100}{62740.521}$	—	$\frac{2365.053 \times 100}{62740.521}$	$\frac{17547.666 \times 100}{62740.521}$	
% 1	79.690	19.519	0.786	—	
% 2	72.089	21.493	—	6.418	
% 3	68.262	—	3.77	27.928	

Composition	1 (a + b + c)	2 (a + b + d)	3 (a + c + d)
SiO_2	16.851	2.841	13.224
Al_2O_3	1.059	1.569	3.121
Fe_2O_3	1.091	0.734	4.323
$Al_2O_3 + Fe_2O_3$	2.15	2.323	7.444

Δ SM(1) = 10.401 SM(2) = 13.932 SM(3) 9.108

Δ AM(1) = 0.514 AM(2) = 1.202 AM(3) = 0.960

	1	2	3	
Δ SM	10.401	13.932	-9.108	
Δ AM	0.514	1.202	0.960	
	24.323	14.666	5.341	44.33
	$\frac{24.323 \times 100}{44.33}$	$\frac{14.666 \times 100}{44.33}$	$\frac{5.341 \times 100}{44.33}$	
	54.868	33.084	12.048	

1 = 24.323 2 = 14.666 3 = 5.341

a = 75.801 b = 17.82

c = 0.885 d = 5.493

Raw-mix composition

SiO_2 % = 17.734 Al_2O_3 % = 1.476

Fe_2O_3 % = 1.362 CaO % = 41.955

LOI % = 35.234

$$F = \frac{1}{0.64766} = 1.544.$$

Clinker composition

SiO_2 %	= 27.381	Al_2O_3 %	= 2.279
Fe_2O_3 %	= 2.103	CaO %	= 64.779

Clinker phases

C_3S	= 37.302	C_2S	= 50.361
C_3A	= 2.481	C_4AF	= 6.399

$2C_3A + C_4AF$ = (2x 2.481) + 6.399

= 11.361 (less than 20 and complies with the ASTM Specification C-150 type V.)

RAW-MIX DESIGN C

The raw materials with the following requirements were applied in our raw mix C

a - Limestone b - Marl c - Gialo sand d - Iron ore

Requirements

$C_3S = 55$ $C_3A = 1.8$

$SM = 2$ $AM = 0.7$

$F_{(a)} = 0.571$ $F_{(b)} = 0.919$

$F_{(c)} = 0.886$ $F_{(d)} = 0.788$

$C_3S_{(a)} = 158.319$ $C_3S_{(b)} = -620.582$

$C_3S_{(c)} = -233.382$ $C_3S_{(d)} = -343.442$

$C_3A_{(a)} = -0.082$ $C_3A_{(b)} = 3.910$

$C_3A_{(c)} = -113.275$ $C_3A_{(d)} = 14.778$

	a	b	o	d	Total
ΔC_3S	158.319	620.582	233.382	343.442	
ΔC_3A	-0.082	3.910	-113.275	14.778	
1	71208.950	-17952.722	568.140		89729.812
2	-7828.103	2311.476		568.140	10707.719
3	-2352.312		2311.476	-17952.722	62616.51
1	$\frac{71208.95x100}{89729.812}$	$\frac{17952.722x100}{10707.719}$	$\frac{568.44x100}{62616.51}$		
2	$\frac{7828.103x100}{10707.719}$	$\frac{2311.476x100}{10707.719}$		$\frac{568.14x100}{10707.719}$	
3	$\frac{2352.31x100}{62616.51}$		$\frac{2311.476x100}{62616.51}$	$\frac{17952.722x100}{62616.51}$	
% 1	79.359	20.008	0.633		
% 2	73.107	21.587		5.306	
% 3	67.638		3.691	28.671	

Composition	1 (a+b +c)	2 (a + b + d)	3 (a+b+c)
SiO_2	17.216	20.475	13.499
Al_2O_3	1.059	1.48	3.173
Fe_2O_3	0.976	0.693	4.288
$Al_2O_3 + Fe_2O_3$	2.035	2.177	7.461

$SM_{(1)}$ = 13.146 $SM_{(2)}$ = 16.129 $SM_{(3)}$ = 1.423

$AM_{(1)}$ = 0.376 $AM_{(2)}$ = 0.995 $AM_{(3)}$ = 0.171

	1	2	3	
SM	13.146	16.129	1.423	
AM	0.376	0.995	0.171	
	4.174	2.783	7.016	13.973
	4.174x100 / 13.973	2.783x100 / 13.973	7.016x100 / 13.973	
	29.872	19.917	50211	

1 = 4.174 2 = 2.783 3 = 7.016

a = 72.229 b = 10.276 c = 2.042 d = 15.453

Raw-mix composition

Si_2 = 15.999 Al_2O_3 % = 2.204 Fe_2O_3 % = 2.582 CaO % = **41.379**

L.O.I. = 35.326

$$F = \frac{1}{0.64674} = 1.546$$

Clinker composition

= 24.734 Al_2O_3 % = 3.407 Fe_2O_3 % = 3,992 CaO % = 63.972

Clinker phases C_3S = 43.855 C_2S = 37.828

C_3A = 2.274 C_4AF = 12.148

2 C_3A + C_4AF = (2x2.274) + 12.148 = 16.696 (less than 20) This means that the calculation result of this raw-mix design complies with the ASTM Specification C-150 Type V.

RAW-MIX DESIGN D

The raw materials applied in our raw-mix design D are:

a - Limestone b - Marl c - Gialo sand d - Pyrite ash

Our requirements are shown as follows:

C_3S = 60 C_3A = 1.8

SM = 2.5 AM = 0.7

$F_{(a)} = 0.571$ $F_{(b)} = 0.919$

$F_{(c)} = 0.966$ $F_{(d)} = 0.788$

$C_3S(a) = 155.464$ $C_3S(b) = -625.177$

$C_3S(c) = -247.499$ $C_3S(d) = -347.382$

$C_3A(a) = 0.082$ $C_3A(b) = 3.910$

$C_3A(c) = -124.991$ $C_3A(d) = 14.778$

	a	b	c		Total
ΔC_3S	155.464	-625.177	-247.499	-347.382	
ΔC_3A	-0.082	3.910	-124.991	14.778	
1	79109.219	-19451.896	559.6	/	99117.715
2	-7880.602	2268.962	---	- 556.6	10706.164
3	-47077.164	---	2268.962	-19451.896	6879.022
1	$\frac{79109.219 \times 100}{99117.715}$	$\frac{19451.896 \times 100}{99117.715}$	$\frac{556.6 \times 100}{99117.715}$		
2	$\frac{7880.602 \times 100}{10706.164}$	$\frac{2268.962 \times 100}{10706.164}$	---	$\frac{556.6 \times 100}{10706.164}$	
3	$\frac{47077.164 \times 100}{68798.022}$	---	$\frac{2268.962 \times 100}{68798.022}$	$\frac{19451.896 \times 100}{68798.022}$	
% 1	79.813	19.625	0.562	---	
% 2	73.608	21.193	---	5.199	
% 3	68.426	---	3.2[illegible]	28.274	

Composition	1 (a+b+c)	2 (a+b+d)	3 (a+c+d)
SiO_2	16.942	20.138	13.419
Al_2O_3	1.036	1.463	3.059
Fe_2O_3	0.942	0.686	4.109
$Al_2O_3 + Fe_2O_3$	1.978	2.149	7.168

SM(1) = 11.097   SM(2) = 14.766   SM(3) = - 4.501

AM(1) = 0.377   AM(2) = 0.983   AM(3) = 0.183

	1	2	3	
Δ SM	11.097	14.766	-4.501	
Δ AM	0.377	0.983	0.183	
	7.127	3.892	6.226	17.245
	7.127x100 / 17.245	3.892x100 / 17.245	6.226x100 / 17.245	
	41.328	22.569	36.103	

1 = 7. 127   2 = 3.892   3 = 6. 226

a = 74.302   b = 12.894   c = 1.423   d = 11.381

Raw-mix composition

SiO_2 % = 16.392 Al_2O_3 % = 1.863

Fe_2O_3 % = 2.028   CaO % = 41.915

LOI % = 35.383

F = 1/0.646 = 1.548

Clinker composition

SiO_2 % = 25.375 Al_2O_3 % = 2.884 Fe_2O_3 % = 3.139   CaO % = 61.884

Clinker phases

C_3S = 47.429 C_2S = 36.970

C_3A = 2.331 C_4AF = 9.952

$2\ C_3A + C_4AF = (2 \times 2.331) + 9.552 = 14.214$

The result complies with the ASTM Specification C-150 Type V.

RAW-MIX DESIGN E

We tried to use the following raw materials in our raw-mix design E

a – Limestone b – Marl c – Gialo sand d – Pyrite ash

C_3S (required) = 5.5 C_3A (required) = 1.8

SM (required) = 2.0 AM (required) = 0.7

$F_{(a)}$	= 0.571	$F_{(b)}$	= 0.919
$F_{(c)}$	= 0.966	$F_{(d)}$	= 0.788
$C_3S_{(a)}$	= 158.319	$C_3S_{(b)}$	= -620.582
$C_3S_{(c)}$	= -192.762	$C_3S_{(d)}$	= -343.442
$C_3A_{(a)}$	= -0.062	$C_3A_{(b)}$	= 3.910
$C_3A_{(c)}$	= -124.991	$C_3A_{(d)}$	= 14.778

	a	b	c	d	Total
ΔC_3S	158.319	-620.582	- 192.762	- 343.442	
ΔC_3A	-0.0812	3.91	- 124.991	14.778	
1	78320.864	-19804.257	568.140	—	98693.261
2	- 7828.103	2311.476	—	568.14	10707.719
3	- 45775.796	—	2311.476	19804.257	67891.529
1	78320,864x100 / 98693.261	19804.257x100 / 98693,261	568.140x100 / 98693.261		
2	7828.103x100 / 10707.719	2311.476x100 / 10707.719		568.14x100 / 10707.719	
3	45775.796x100 / 67891.529		2311.476x100 / 67891.529	19804.257x100 / 67891.529	
% 1	79.358	20.066	0.576		
% 2	73.107	21.587	—	5.306	
% 3	67.425	—	3.405	29.170	

Composition	1 (a+b+c)	2 (a+b+d)	3 (a + c + d)
SiO_2	17.273	20.470	13.773
Al_2O_3	1.040	1.480	3.137
Fe_2O_3	0.956	0.693	4.230
$Al_2O_3 + Fe_2O_3$	2.002	2.173	7.367

$SM_{(1)} = 13.269$ $SM_{(2)} = 16.129$ $SM_{(3)} = 0.961$

$AM_{(1)} = 0.377$ $AM_{(2)} = 0.995$ $AM_{(3)} = 0.176$

	1	2	3	
△ SM	13.269	16.129	- 0.961	
△ AM	0.377	0.995	0.176	
	3.795	2.698	7.122	13.615
	$\frac{3.795 \times 100}{13.615}$	$\frac{2.698 \times 100}{13.615}$	$\frac{7.122 \times 100}{13.615}$	
	27.874	19.816	52.31	

1 = 3.795 2 = 2.698 3 = 7.122

a = 71.877 b = 9.871 c = 1.942 d = 16.31

Raw-mix composition

SiO_2 % = 16.077, Al_2O_3 % = 2.226, Fe_2O_3 % = 2.617

CaO % = 41.366 LOI = 35.157.

$$F = \frac{1}{0.64843} = 1.542.$$

Clinker composition

SiO_2 = 24.791 Al_2O_3 % = 3.432

CaO % = 63.786 Fe_2O_3 % = 4.035

Clinker phases C_3S = 42.435 C_2S = 39.063

C_3A = 2.268 C_4AF = 12.279

$2\,C_3A + C_4AF$ = (2x2.268)+ 12.279 = 16.815

The result complies with the ASTM Specification C-150 Type V.

Annex IV

COST OF PRODUCING NORMAL PORTLAND CEMENT AT LCC PLANTS

A. Raw materials to storage stage

Item	Hawari Plant 1979 (LD)	(%)	Benghazi Plant 1977 (LD)	(%)	Benghazi Plant 1978 (LD)	(%)	Benghazi Plant 1979 (LD)	(%)	+30% of maximum cost (LD)	(%)
Limestone										
Crushing	591 771.1		428 433.4		406 954.0		410 760.8		769 302.4	
Storage	78 976.3		16 736.8		40 146.4		38 852.5		102 669.1	
Total	670 747.4		445 170.2		447 100.4		449 613.3		871 971.6	
Mean production costs per ton										
Crushing	1.8	88.0	0.8	96.0	0.7	91.0	1.0	91.0	2.4	88.0
Storage	0.2	12.0	0.0	4.0	0.1	9.0	0.1	9.0	0.3	12.0
Total	2.0	100.0	0.8	100.0	0.8	100.0	1.1	100.0	2.7	100.0
Clay (marl)										
Crushing	224 208.7		141 379.8		174 837.7		139 009.8		291 471.3	
Storage	15 693.0		21 111.9		28 842.6		25 357.3		20 400.9	
Total	239 901.7		162 491.7		203 680.3		164 367.1		311 872.2	
Mean production costs per ton										
Crushing	1.1	93.5	0.5	87.0	0.6	86.0	0.652	85.0	1.5	93.5
Storage	0.1	6.5	0.1	13.0	0.1	14.0	0.119	15.0	0.1	6.5
Total	1.2	100.0	0.6	100.0	0.7	100.0	0.771	100.0	1.6	100.0

(Tons per year)

Total production	Hawari Plant 1979	Benghazi Plant 1977	Benghazi Plant 1978	Benghazi Plant 1979
Limestone	327 942.3	527 577.9	572 586.7	420 472.1
Marl	198 851.2	263 140.3	306 996.1	213 108.7

B. Grinding, mixing and homogenization of raw-mix stages

Item	Hawari Plant 1979 (LD)	(%)	Benghazi Plant 1977 (LD)	(%)	1978 (LD)	(%)	1979 (LD)	(%)	+30% of maximum cost (LD)	(%)
Grinding stage	537 369.0		463 739.1		819 182.7		575 488.0		698 579.7	
Storage stage	92 348.3		42 720.5		89 276.5		76 763.5		120 052.9	
Raw materials	1 041 056.0		585 049.2		625 926.3		592 966.6		1 353 372.8	
Total	1 670 773.4		1 091 508.9		1 534 385.6		1 245 218.1		2 172 005.4	
Mean production cost per ton										
Grinding stage	0.9	32.2	0.6	42.5	1.0	53.4	0.9	46.2	1.2	32.2
Storage stage	0.2	5.5	0.1	3.6	0.1	5.8	0.1	6.2	0.2	5.5
Raw materials	1.8	62.3	0.8	53.6	0.7	40.8	1.0	47.6	2.3	62.3
Total	2.9	100.0	1.4	100.0	1.8	100.0	2.0	100.0	3.7	100.0
	(Tons per year)									
Total production	579 333.6		769 315.1		846 489.1		620 364.1			

(Hawari budget year 1979: cost of crushed raw gypsum per ton plus 30% = LD 6.5)

C. Burning of raw-mix in rotary-kiln stage

Item	Hawari Plant 1979 (LD)	(%)	Benghazi Plant 1977 (LD)	(%)	Benghazi Plant 1978 (LD)	(%)	Benghazi Plant 1979 (LD)	(%)	+30% or maximum cost (LD)	(%)
Clinker production	1 396 591.8		1 228 771.2		1 675 011.8		1 657 682.2		1 815 569.3	
Clinker storage	50 514.9		39 665.8		59 473.9		125 885.0		65 669.4	
Raw materials	1 662 541.0		1 122 923.6		1 518 519.2		1 238 011.6		2 161 303.3	
Total	3 109 647.7		2 391 360.6		3 253 004.9		3 021 578.8		4 042 542.0	
Mean production cost per ton										
Clinker production	4.0	45.0	2.6	51.4	3.3	51.5	4.5	54.9	5.2	45.0
Clinker storage	0.1	1.6	0.1	1.6	0.1	1.8	0.3	4.2	0.2	1.6
Raw materials	4.8	53.4	2.4	47	3.0	46.7	3.3	40.9	6.2	53.4
Total	9.0	100.0	5.1	100.0	6.5	100.0	8.1	100.0	11.7	100.0
	(Tons per year)									
Total production	346 118.2		467 988.1		504 155.5		371 114.5			

D. Clinker grinding stage (Cement production)

Item	Hawari Plant 1979 (LD)	(%)	Benghazi Plant 1977 (LD)	(%)	1978 (LD)	(%)	1979 (LD)	(%)	+30% of maximum cost (LD)	(%)
Grinding clinker + gypsum	544 783.3		483 548.1		628 822.8		601 712.4		708 218.3	
Cement storage	61 094.3		594 303.6 a/		48 244.2		47 859.7		79 422.7	
Raw materials (clinker + gypsum)	3 290 242.2		2 345 480.8		2 794 218.9		3 120 032.8		4 277 314.9	
Total	3 896 119.9		3 423 332.4		3 471 285.9		3 769 604.9		5 064 955.9	
Mean production cost per ton										
Cement grinding	1.3	14	1.1	14.1	1.4	18.1	1.4	15.9	1.7	14
Cement storage	0.2	1.6	1.3	17.4	0.1	1.4	0.1	1.3	0.2	1.6
Cement constituents	8.1	84.4	5.2	68.5	6.1	80.5	7.2	82.8	10.5	84.4
Total	9.5	100.0	7.5	100.0	7.5	100.0	8.7	100.0	12.4	100.0

(Tons per year)

	Hawari Plant 1979	Benghazi Plant 1977	1978	1979
Total cement production	408 096.6	455 124.3	459 917.2	434 558.6

a/ Storage cost is high in 1977 as distribution of fixed assets of line three was not taken into consideration. It was agreed to indicate depreciation of assets without any distribution on the last stage.

E.(a) Packing and loading cement stage

Item	Hawari Plant 1979 (LD)	Benghazi Plant 1977 (LD)	Benghazi Plant 1978 (LD)	Benghazi Plant 1979 (LD)	+30% of maximum cost (LD)
Salaries	100 981.5	67 030.3	123 643.9	119 362.9	155 171.7
Employee transport	21 325.2	13 044.0	14 808.9	20 011.1	26 014.4
Depreciation	99 902.4	15 780.8	39 946.1	39 830.8	51 780.1
Spare parts	17 518.8	11 83[illegible]	23 957.8	17 744.7	23 063.2
Electricity	9 245.9	4 802.1	8 607.9	5 587.1	7 263.3
Maintenance and repairs	36 074.5	--	4 512.6	117 352.1	152 557.8
Insurance	1 110.1	--	1 463.4	1 077.9	1 401.3
Fuel	1 303.9	9.5	344.3	--	--
Indirect expenses	--	933.5	--	--	--
Other expenses	--	379.4	694.1	78.9	102.5
Employee benefits	--	388.5	--	--	--
Contracted services (experts)	10 436.4	--	--	2 242.6	2 915.4
Total	297 898.7	114 2[illegible]9	217 978.8	323 288.2	420 274.1
Paper bags	293 557.1	445 441.3	383 803.8	316 177.2	579 073.6
	(Tons per year)				
Total loaded cement	409 926.4	445 780.3	460 397.7	433 913.1	

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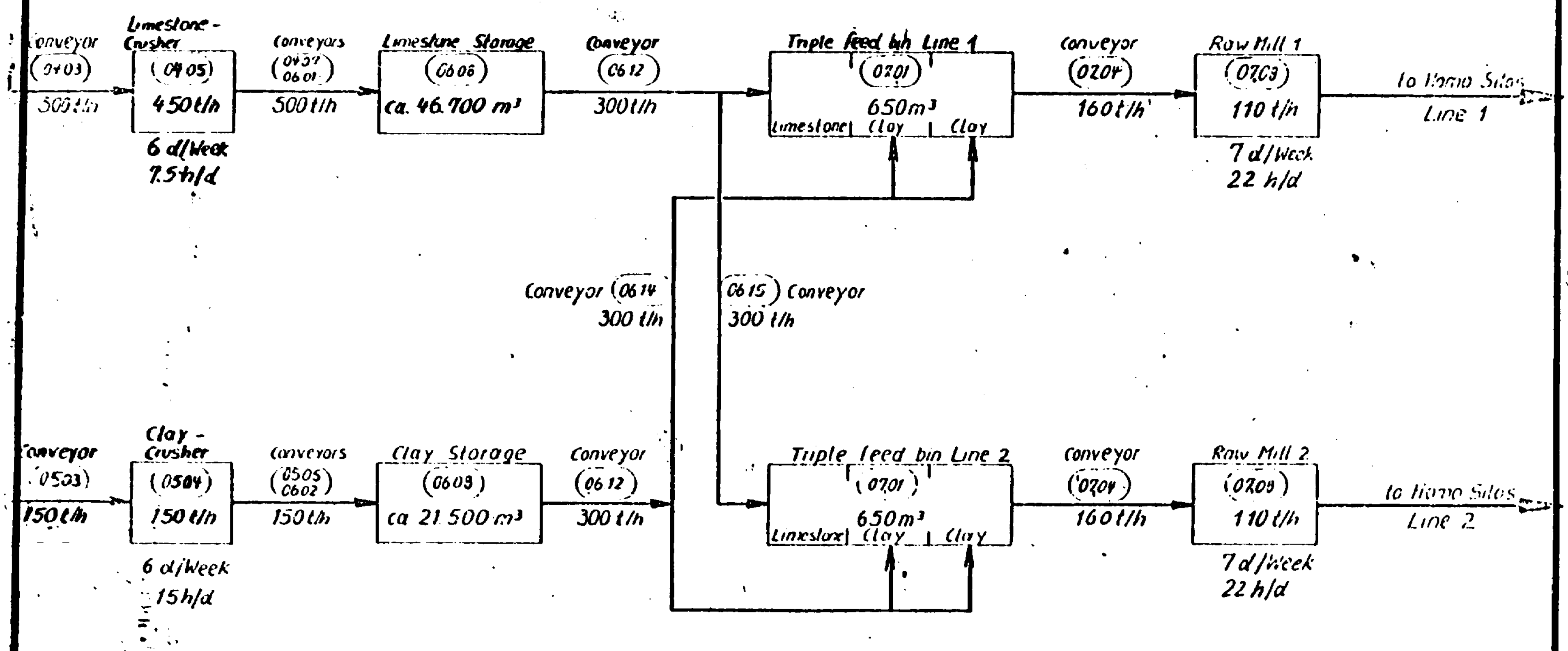
E.(b) Packing and loading stage - cost per ton

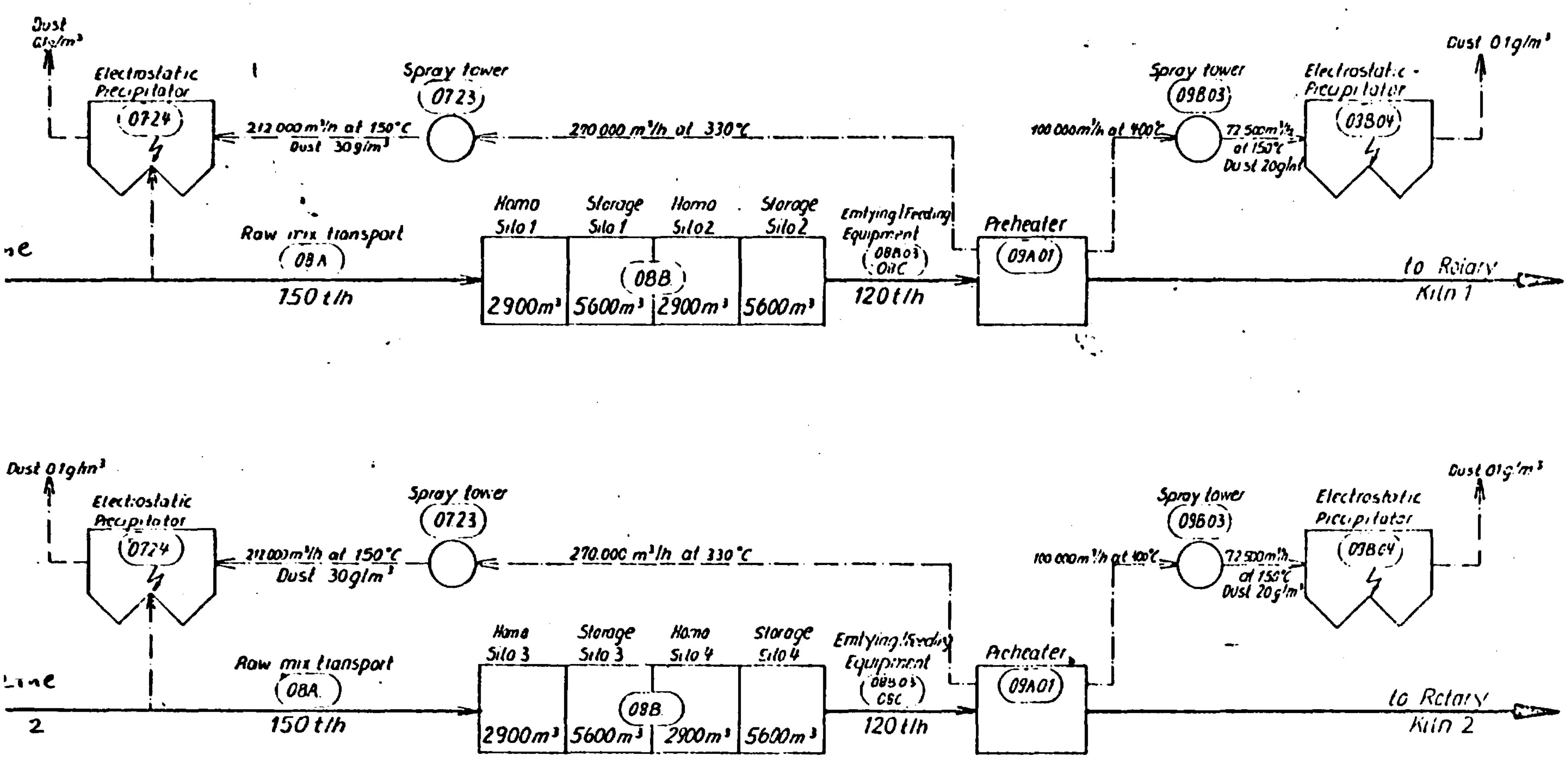
Item	Hawari Plant 1979 (LD)	Benghazi Plant 1977 (LD)	Benghazi Plant 1978 (LD)	Benghazi Plant 1979 (LD)	+30% of maximum cost (LD)
Salaries	0.2463	0.150	0.2685	0.2750	0.3576
Employee transport	0.0520	0.029	0.0321	0.0461	0.05995
Depreciation	0.2437	0.035	0.0867	0.0917	0.1193
Spare parts	0.0427	0.026	0.0520	0.0408	0.0532
Electricity	0.02255	0.010	0.0186	0.0128	0.01674
Maintenance and repairs	0.0880	--	0.0098	0.2704	0.35159
Insurance	0.0027	--	0.00317	0.00248	0.00323
Fuel	0.0031	0.00002	0.00074	--	--
Indirect expenses	--	0.002	--	--	--
Other expenses	--	0.00085	0.0015	0.00018	0.000236
Employee benefits	--	0.00087	--	--	--
Contracted services (epxerts)	0.0254	--	--	0.00516	0.006718
Total per ton	0.7264	0.2537	0.4731	0.7446	0.96856
Paper bags per ton	0.7161	0.9992	0.8336	0.7286	1.3345
Packing cost per ton	1.4425	1.2529	1.3067	1.4732	2.30306

Annex V

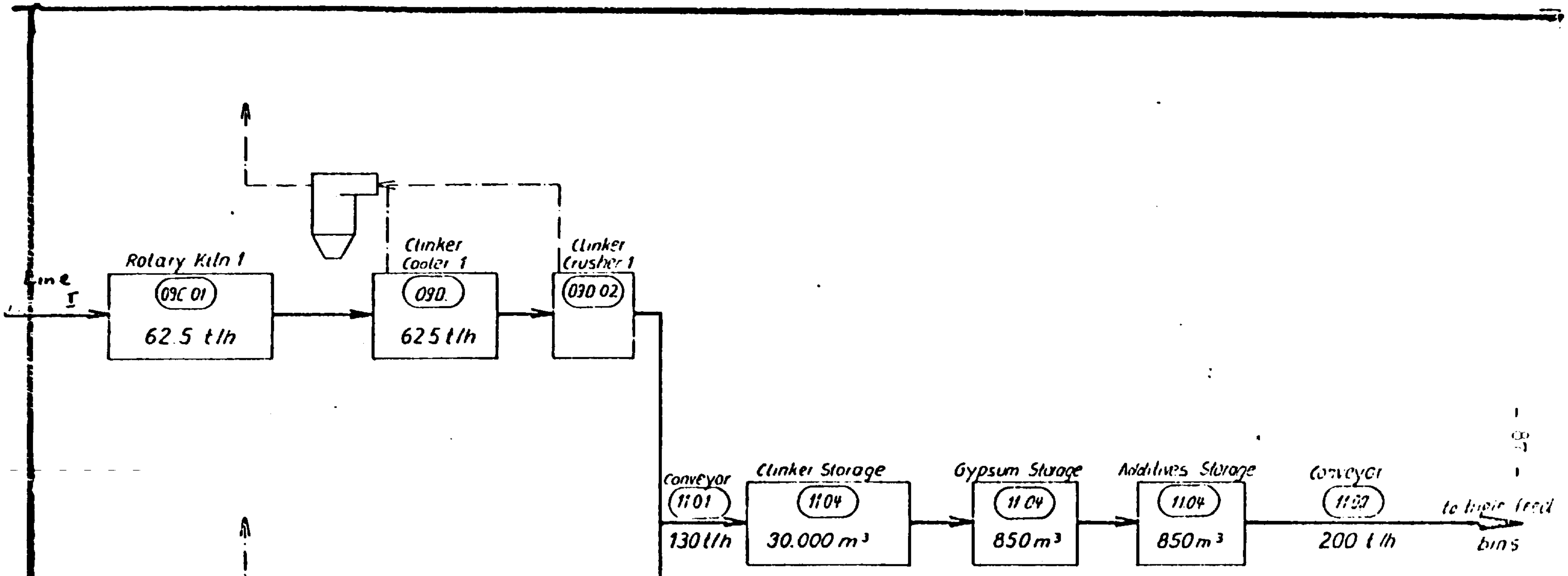
DIAGRAMS OF PRODUCTION PROCESSES IN LCC CEMENT PLANTS



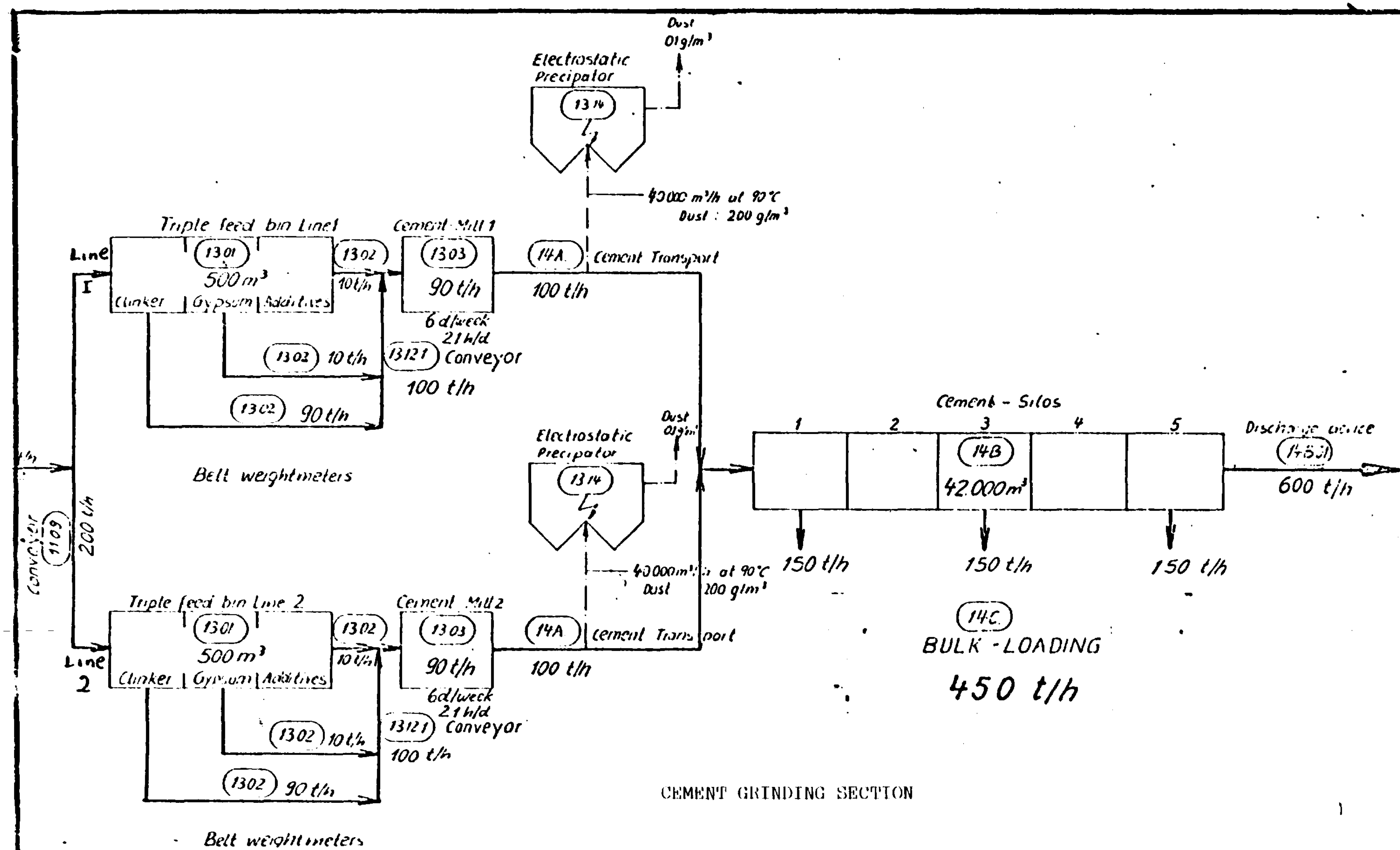
RAW-MATERIAL GRINDING SECTION



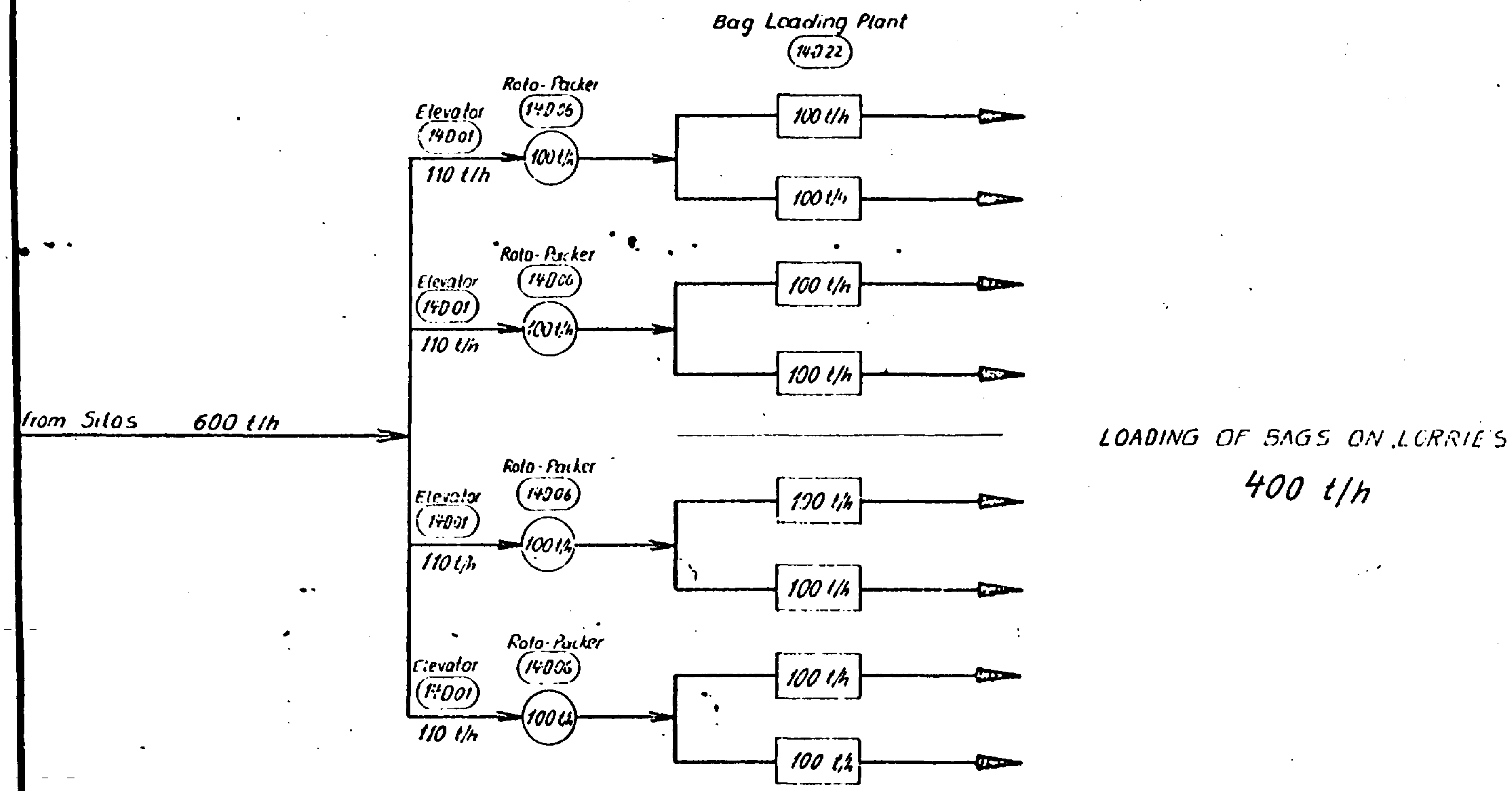
RAW-MATERIAL HOMOGENIZING SECTION



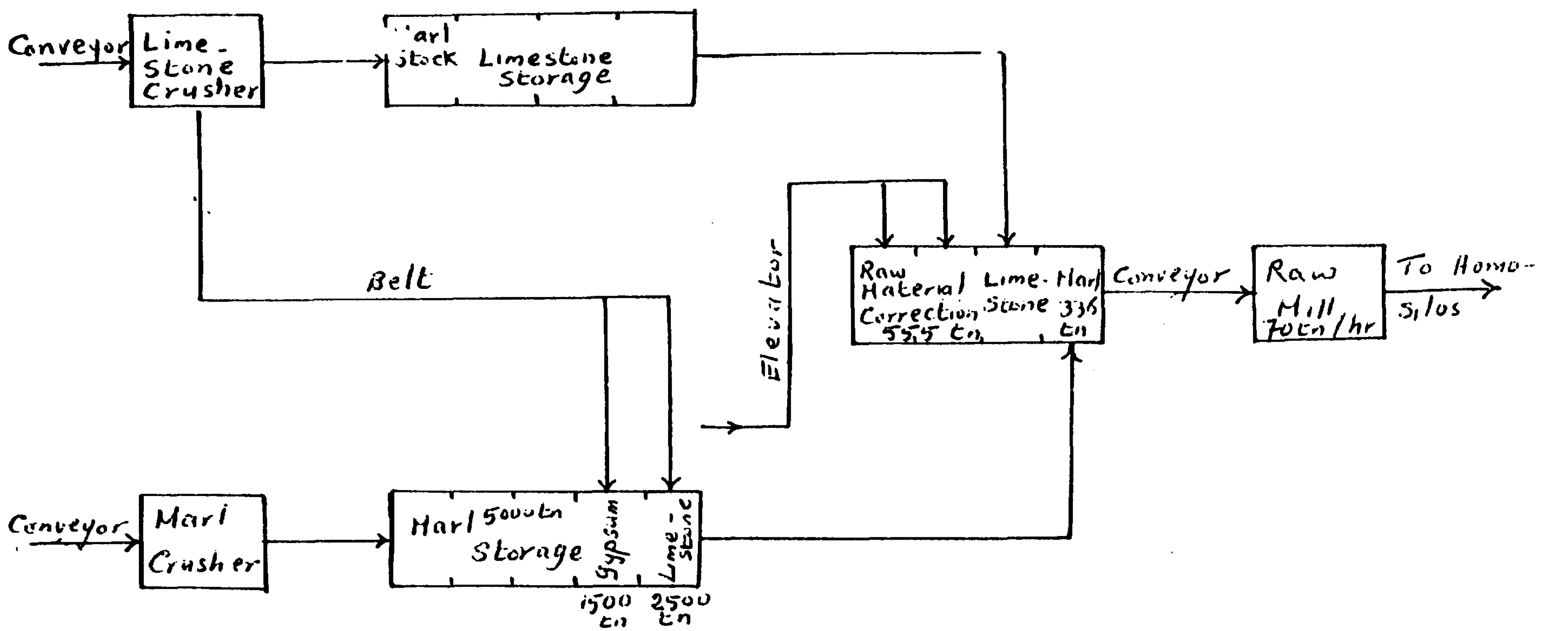
CLINKER PRODUCTION



CEMENT GRINDING SECTION



CEMENT PACKING AND DESPATCH SECTION

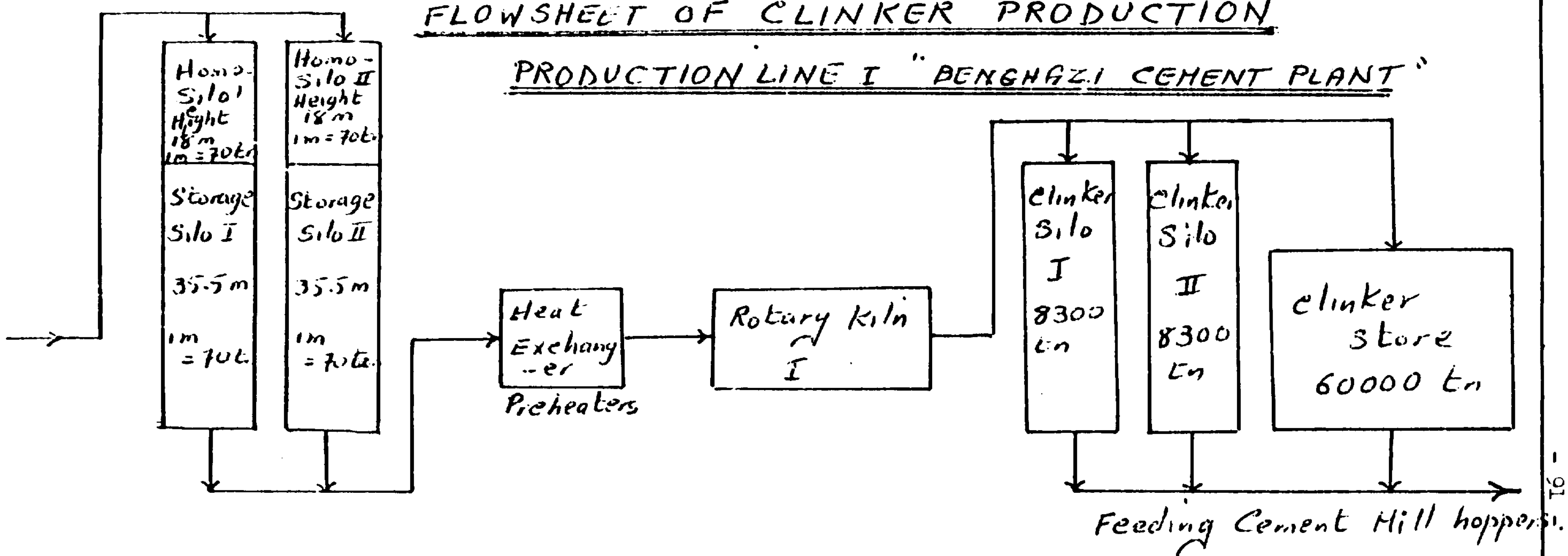


FLOWSHEET OF PRODUCTION LINE I "BENGHAZI CEMENT PLANT"
RAW MATERIALS CRUSHING + Grinding.

- For Production Line II
  Feeding of Raw Materials is Supplied from the Same R.M Storage
- For Production Line III
  Independent Raw Materials Storages: 4 storages "Limestone" of 12000 tns + 4 Stores "Marl" Capacity 12000 tns. Feeding of gypsum from Production Line I stores.

FLOWSHEET OF CLINKER PRODUCTION

PRODUCTION LINE I "BENGHAZI CEMENT PLANT"



— For Production Line II

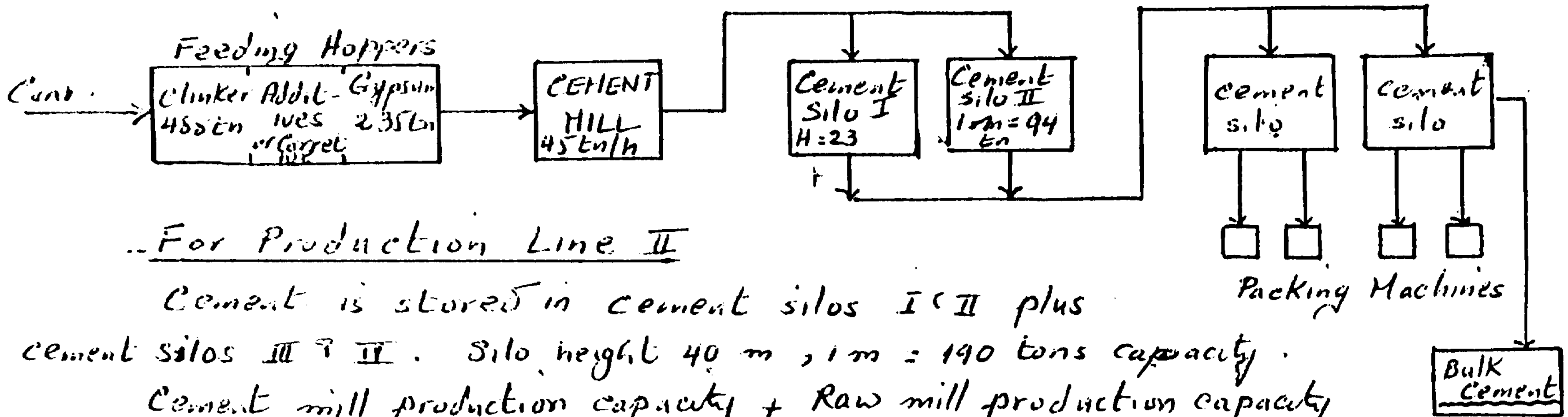
2 Raw Mix Stores (Silos). Height of Silo 40 m. Capacity of one meter = 160 tons, + 2 Homo Silos, Height = 18 m Capacity of one meter = 160 tons. Storage of clinker in 2 clinker Silos (mentioned above) + the same clinker store used for Production Line I "mentioned above"

— For Production Line III

2 Raw Mix Silos with the same height and capacities are serving Line III + 2 Homo silos with the same capacity of line II. Clinker store serve Line III

FLOWSHEET OF CEMENT GRINDING & DESPATCHING

PRODUCTION LINE I "BENGHAZI CEMENT PLANT"



– For Production Line II

Cement is stored in cement silos I & II plus cement silos III & IV. Silo height 40 m, 1 m = 190 tons capacity.

Cement mill production capacity + Raw mill production capacity are double production capacity of line I. Storage capacity of Marl hopper = 310 tons, Limestone = 368 tons, Gypsum = 210 tons, Clinker = 370 tons, Additive = 150 tons.

– For Production Line III

Cement is stored in cement silos VI & VII of the same capacity of cement silos I & II plus cement silo V, Height = 40 m. 1 m = 190 tons (capacity). The production capacities are the same of production Line II capacities. Cement to be despached through 2 rotary packing machine of 100 tn/h capacity

83.06.23