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INVESTIGATION OF CONCRETE STRUCTURES IN THE AMRAN CEMENT PLANT

SI/YEM/86/801

YEMEN ARAB REPUBLIC

Technical report: Strength assessment of the structure *

Prepared for the Government of the Yemen Arab Republic
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Pranshanker Dave, UNIDO consultant

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Vienna

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PREFACE

Many developing countries have made rapid strides in industrialisation in the past few decades. Growth in local scientific and technological education has often been unable to keep pace with the growth in the industry. So, many developing countries depend on the developed countries, not only for the engineering consultancy and construction purposes, but also for occasional problem solving. UNIDO has provided assistance in such circumstances with admirable success. While the international consultants and contractors themselves are competent to solve such problems, often the clients seek an independent and unbiased opinion of the UN expert.

Central Planning Organisation (CPO)--Ministry of Economy and Industry (MOEI) of Yemen Arab Republic (YAR)--had established a modern cement plant at Amran, namely Amran Cement Plant (ACP), under the consultancy of Bureau Central d'Etudes pour les Equipments d'Outre Mer (BCEOM) of France, and general contractorship of Ishikawajima - Harima Heavy Industries Co. (IHI) of Japan, and had commissioned the same in 1982. Noticing distress in the reinforced concrete structures of ACP, MOEI approached UNIDO, Vienna, Austria, to provide a R/C Structures expert who could inspect the structures and make necessary recommendations. This writer was commissioned by UNIDO to achieve this goal.

This report contains the results of several site visits, reviews of the technical drawings, calculations, reports, published literature, site measurements and the fact-finding discussions with the operating people. Procedures followed to arrive at unbiased, independent conclusions are documented, causes of distress are reported and recommendations are made. Attempt is made not to duplicate the works done in this regard by others, not to collect data that would not contribute to the ultimate objective and not to indulge in details that would violate the temporal constraints, without being conducive to the attainment of the goal. The approach throughout is of a practical angle rather than a theoretical one. References used and documents seen are listed.

The report is being presented to UNIDO, Vienna, Austria, in total fulfilment of the terms of this assignment, and the writer is confident that ACP will have no structural weakness after the implementation of the recommendations made in this report. The writer has thoroughly enjoyed this assignment and hopes the report will be found in order.

P.C. Dave

CHAPTER 1
TERMS OF REFERENCE

1. GENERAL

UNIDO's "job description" containing the purpose of the project, duties, background information, and the qualification of the specialist, in effect, constitutes the terms of reference. The said job description is included in this report as Appendix A. Some features and modifications of the terms of reference are analysed in what follows.

1.1 URGENCY

Considering the urgency of this project, the writer was to report to the ACP site as soon as possible and the briefing and debriefing were proposed to be at UNDP office, Sana'a. Since the implied terms of reference were very clear and since the writer had previous experience of the designing, constructing and trouble-shooting of cement plant structures in two other developing countries, and had met with structural distress problems in cement plants and other industrial projects in his active career of over twenty-five years, the briefing could be minimal.

1.2 EXTENT OF WORK

Apprehending a critical structural situation at ACP, UNIDO had contemplated the forensic type of investigation and failure analysis and made the scope of duties all-encompassing. Again, due to time constraint, this investigation had to be completed in one months time, inclusive of travel time and time for preparation of the report. Had the condition at ACP been as serious as feared by UNIDO, the writer wonders if the job could have been completed as scheduled.

1.3 REVISED TECHNICAL TERMS OF REFERENCE

Considering the actual conditions at ACP, the revised terms of reference may be: Inspect all the structures, identify the distressed components, study the relevant documents, establish the cause of defects, draw conclusions and make recommendations. Formulate the solutions and present them in the form of a report that should dispel all doubts and lead to a practical corrective course of action. Address also the problem of cracks in the block work of the housing. Follow the spirit of the original terms of reference and include a general overview of the plant, including the soil survey and consequent long-term future problems, if any.

CHAPTER 2
INTRODUCTION

2.0 GENERAL

The Cement Industry is the backbone of nation-building. Cement plants are very important to YAR. There is so much construction going on all around that one hardly needs statistics to convince oneself of the demand for cement. Two cement plants in the country work round the clock to meet the demand. They simply cannot afford to shut down the plants for any length of time on any account.

2.1 AMRAM CEMENT PLANT (ACP)

Located near Amran, on the flat farmland, surrounded by dry, rugged mountains, ACP is 50 KM north-west of Sana'a. Conceived in 1978, the plant started production in 1982, with a designed capacity of 500,000 tons per year. It is a national enterprise under MOEL. Consultants were BCEOM of France; IHI of Japan were the general contractors. Soil investigation was subcontracted to RSI of Japan. All the civil works of the main plant, the ancillary buildings, and the housing work were subcontracted to JWD of Korea, by IHI.

The plant consists of Limestone Crushing and Conveying facilities, Limestone Mixing facility, Clay and Pyroclastic Material Crushing and Conveying facilities, Gypsum Crushing and Conveying facilities, Raw Material Grinding Mill, Raw Meal Homogenization and Storage Silos, Raw Meal Feeding system, Rotary Kiln, Clinker Cooling system, Clinker Conveying system, Clinker Storage Silos, Cement Grinding Mill, Cement Storage Silos, Cement Packing Plant and Cement Loading Plant. The ancillaries include the Power House, Boiler House, Compressor House, Water Reservoir and Cooling Towers, Oil Tanks, Maintenance Shop, Warehouse, Canteen and Office Buildings. The Housing facilities include Villas, Dormitary, Garages, and Elevated Water Tank. On the mining side are included the Explosives Store, Magazine, etc.

2.2 CIVIL WORKS

The civil works consist of R/C Foundations and Floors, R/C Building Frames, R/C Equipment Foundations, R/C Silos, R/C Tunnels, R/C Trenches and Pits, R/C Stairs and R/C Reservoirs. The R/C Beams supporting the machines and the R/C Portal supporting the Kiln constitute a special kind of equipment support. Structural steel is used in Superstructures, Conveyor Supports, Crane Girders, Walkways and Platforms, Ducting and Equipment Supports, etc.

In operating industrial production facilities, the structures are often taken for granted and treated with indifference. They do not have the sophistication of machines and glamour of the electronics of control rooms. They rarely cost more than 25 percent of the project cost and usually have secondary character. However, these structures support and shelter the equipment and are more difficult to repair or replace than machines. Manufactured at site, they often lack the quality control, and are prone to distresses from the environment and the loads they withstand. Treated without due respect or abused, they revolt and cause disasters. ACP's awareness of the structural distress is commendable.

2.3 GENERAL SURVEY: A WALK-THROUGH

In order to get the feel of the problem of cracking, and to evolve a methodology for detailed study, a first walk-through was carried out without reference to any drawings, documents, measurements or tests; a mere visual inspection revealed the following condition of the structures, presented in order of increasing severity:

2.3.1 Structural steel work looks well proportioned, well braced and neat. NO problems at all.

2.3.2 Silos look fine. Quality of concrete is good. Wall thickness looks ample. Finish could be better. Cracks are few and very fine. NO problems at all.

2.3.3 Concrete building columns, girders, beams, slabs all look very good. Only a few have cracks. Cracks are fine and unimportant. Little or no vibrations. Some problems.

2.3.4 Concrete in almost all machine foundations and building pedestals looks fine. Some have cracked. Some problems.

2.3.5 Concrete around some machine base plates and base frames, and around some steel column base plates is cracked. In most cases this is a second stage concrete, and cracking is of no structural consequence.

2.3.6 Non-load-bearing block work is generally good. A few have cracks.

2.3.7 Concreting in tunnels is good. A few shrinkage cracks caused by lack of control or expansion joints. They look serious and bad but do not affect the structural integrity. Leakage problem.

2.3.8 Top pedestals of Kiln Hood and Kiln Supports have second stage concrete cracked. Along with this, the structural concrete has also cracked. These are serious for machines. They are also of structural consequence. One short stair is badly cracked.

2.3.9 The three two-storied portal supports for the Kiln are cracked. The middle support is very bad. Structural integrity can be in question. This is very serious.

2.3.10 Load-bearing block work in houses looks terrible. Many cracks. Does not look like settlement problem. Structural safety seems to be in doubt.

2.3.11 Concrete and block work in all ancillary works are generally good. No problems. Few bad cases of block work cracks are in Power House, Cement Testing Laboratory and in Canteen.

2.4 HISTORY OF DEFECTS

The Engineer who was in charge of supervision of civil works on ACP site during construction reports that the cracks in silos and tunnels were noticed immediately after construction; cracks in beams appeared in about two months time after the construction was handed over to ACP, and cracks in the Kiln Supports and Kiln Hood pedestal had developed after operations started. The second stage concrete has been cracking ever since the operations started.

CHAPTER 3
METHODOLOGY

3.1 GENERAL

On the basis of the distress noticed in the general survey, the following scheme was established in order to ensure that all the factors influencing the structural integrity and durability are thoroughly reviewed. Generally, the site visits were organised in the morning half of the day, six days a week, and the afternoons, the evenings, and the holidays were reserved for document survey. Though ACP was very cooperative in locating documents, they often took longer in retrieving them. It must be appreciated, however, that in an operating plant, where daily problems are to be attended preferentially, and production targets are to be met, searching for documents, stored away safely five years back, can be really demanding. It goes to the credit of ACP that the documents were protected so well, and it goes to the credit of IHI that excellent documentation was provided.

3.2 FACTORS CAUSING DISTRESS

Any one or some combination of the following can be responsible for the observed distress:

3.2.1 Soil condition.
3.2.2 Design assumptions.
3.2.3 Design calculations.
3.2.4 Errors in drawings.
3.2.5 Faulty construction.
3.2.6 Weakness in material.
3.2.7 Natural disasters.
3.2.8 Accidents during Structural/Mechanical erection, Commissioning or Initial operations.

3.3 DOCUMENTS TO BE STUDIED

Based on the above factors that can influence the structural performance, the following corresponding documents were to be studied:

3.3.1 Soil Investigation Report, Laboratory Studies and Analysis.

3.3.2 Design Criteria, Relevant Codes and Standards.

3.3.3 Analysis and Design Calculations, Reference Literature.

3.3.4 Design and Construction Drawings.

3.3.5 Deviation Reports, Acceptance Certificates.

3.3.6 Concrete Test Results, Quality Control Programme.

3.3.7 History of Climatic Phenomena, Meteorological Data.

3.3.8 Documented Accidents, Talks with Operation People.

3.4 STUDIES BY OTHERS

In order not to be biased by the conclusions of the other parties, it was decided that such documents be studied last.

3.5 AIMS AND OBJECTIVES

The aims and objectives of this study are as follows:

3.5.1 Identify all distresses.

3.5.2 Classify them according to severity.

3.5.3 Establish the cause/causes for distresses.

3.5.4 Arrive at conclusions.

3.5.5 Make recommendations.

NOTE:

Concrete test results and meteorological data could not be traced in time to be studied and hence are not included in this report. Concrete quality is not in question anywhere in the structures of ACP, and ACP engineer confirms that no concrete test result fell below the requirement. This is reassuring and sufficiently corroborates the visual quality inspection. Core testing and chemical analysis were also not done for the same reason. The cause of cracking is definitely not of material origin. In some places, poor workmanship and a "covering-up" attitude of the contractor were noticed. This could be serious for the structures.

CHAPTER 4
DOCUMENT SURVEY

4.0 GENERAL

Though the site visits and the study of the relevant documents continued simultaneously and progressively, the findings of the site visits and the documents are reported under separate chapters for ease of presentation. The advantage of this simultaneous document/site study was that emphasis on some aspects of each could be varied and the findings could be readily correlated The observations made on various documents reviewed and comments made on them are presented in what follows. An attempt is made to achieve objectivity and no criticism is intended.

4.1 SOIL INVESTIGATION AND FOUNDATION TYPE SELECTION

The soil investigation was carried out by RSI of Japan under sub-contract from IHI. The site work included taking 16 test borings, obtaining samples for laboratory tests, and carrying out SPT--N values; laboratory investigations and tests were exhaustive. The test borings were sited, one at each location of the important structure, such that the cross sections of the substrata could be established. Based on this investigation, RSI came to the following conclusions:

A) Geological fault does not exist at this plant site.

B) Ground water table is nine metres below the ground level (ground zero, incidentally, is at EL.2200M above MSL).

C) At cement silo location (B.H.3), the allowable soil bearing capacity is 7.3 T/M^2.

D) At Fuel Oil Tank location (B.H.1), the allowable soil bearing capacity is 9.2 T/M^2.

E) At Raw Material Storage location (B.H.9), the allowable soil bearing capacity is 5.7 T/M^2.

F) Total settlement at the above three locations will be respectively 41.9cm, 23.5cm and 48.4cm.

G) If piles are used, they should rest in the gravel layer.

The above report was submitted to IHI in January, 80. Suspecting the samples to be disturbed, IHI discarded some laboratory tests and conclusions of RSI, and based on N values and other soil parameters, recalculated the allowable soil capacities at various depths and at the locations of various facilities. These, after rounding off, are summarised in Table 1. IHI also carried out the slip-circle analysis for the cement silos and arrived at the safety factors of 5.4 and 2.3 against failures.

TABLE 1

B.H. NO	FACILITY	ALLOWABLE BEARING CAPACITY T/M² AT DEPTH M. BELOW THE GL																				
		0.0	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10	15
10	LS Crushing														47							
9	LS Mixing Bed	77		56				50														
6	RM Grinding			31		33		35														
6	RM Homo Silo			41			33		53		75											
6	Pre Heat Tower			34																		
6	Rotary Kiln			32		34		36	55													
5	Burner/Cooler				30		94		113													
4	Clinker Silos										58		67		86		117		108		140	48
22	CEM. Grinding			66				79		43		60		82		101		90		141		
3,21,22	CEM. Silos.			72			70		74		47		70		92							
21	CEM. Pack. Load.			69			49															
7	Fuel Oil Tanks	29	31																			
1	WK.Shop/W.House			60																		
7	Powerhouse			44		76						41										
2	Off/CANT./C.Hse.			57																		

On the basis of the chemical analysis of the soil carried out by RSI, and on the basis of their own calculation on bearing capacity, IHI concluded that the sulphate resistant cement and piles were not required. These conclusions resulted in substantial savings in the civil works cost. IHI's findings are presented in their report titled "Recommendation for Foundation Type", dated March 8, 1980.

4.1.1 COMMENTS

Although the writer is not a geotechnical expert, some comments, based on his past experience, are offered, especially because the behaviour of the structures have a bearing on the soil conditions and assumptions.

At the outset it can be seen that the RSI's conclusions on the bearing capacity of the soil are quite inconsistent with the consistently large N values, which are greater than 20 at most locations and along most of the strata, and are less than 10 at only a few locations and at stratas varying from one metre to three metres in thickness. IHI's conclusion in this matter seems reasonable. But the bearing values arrived at are rather daring. It is felt that some confirmatory plate bearing tests could have been easily carried out at appropriate levels at the time of the excavations for the foundations, at a nominal extra cost, especially in the light of the fact that the laboratory compression tests were discarded. Capacities of clays are often deceptive and vary with moisture. Long-term settlements are to be expected but, IHI is correct in their conclusion, not of the order of 400mm. Perhaps less than half this figure could be expected over the life of the plant. Some settlements are to be expected in the case of cement silos whose zone of influence would reach much farther down. Significant differential settlements are not to be expected since the compressible stratas are rather uniformly even at most places. However, a small, uneven settlement could result in the tilting of machine foundations, and cause unusual wearing in bearings and can be a constant headache in maintenance. A much smaller bearing pressure under machine foundations would have been desirable. Also, a local soft patch, not revealed by the discrete boring locations, may cause local settlement larger than the surrounding structures. Another striking feature of this investigation is that the borings are discontinued where the gravel layer was reached, maximum depth of boring being about 21 metres. At least one boring should have been extended up to 50 metres. But perhaps the strata is well known from the tube well bores of 200 metres or deeper, and the need to explore gravel layer was not felt. This, however, is not stated. The basis of RSI's conclusion that the geological fault does not exist on this site is also not known.

4.2 DESIGN CRITERIA

This document of 135 pages of clearly stated principles, specific codes and standards and well illustrated loading patterns is a commendable and comprehensive work of IHI, providing a first-class backbone to all the steel and concrete analyses and designs. Some detailing in steel works is of great practical value in easing the site erection. Despite these and many other fine features of this design document, there are some aspects where the comments are due.

4.2.1 COMMENTS

Reference to AASHTO standards for road work and ACI 531-79 for masonry work would have been in order. Reductions in allowable stresses of concrete and reinforcement in machine foundations and in components of buildings directly under machine foundations, would have resulted in better structures. Advice to provide substantial haunches with diagonal bars in case of Kiln Supports would ensure a better durability. ACI 318 is a building code and cannot be applied to machine foundations. Especially the frame type machine foundations must be designed with considerably lower stresses, must have haunches and must be substantial. At least 16mm bars at 200mm should have been specified as a minimum in block foundation sides and tops. Codes of practice for designing TG and other machine foundations and authorities like Major and Barkan advocate conservatism in allowable stresses. This should have been followed. Criteria of assuming reduced stresses help in fatigue problems, not so well understood in concrete and rebars. ACI 215R-74 could throw light on this. Some practices of bridge construction -- pour sequence for instance -- could control cracking due to volume change, says Ref. 30. No one in the world designs supports of machines as per ACI 318.

4.3 CALCULATIONS FOR SILOS

Calculation for Cement Storage and Clinker Storage Silos, a fine documentation of over two hundred pages, is very thorough and methodical. Awareness to details, and need for grid analysis of beam systems, meticulousness in loadings, and care in stress checks, and vigilance in crack control checks, are commendable. Walls are substantial and reinforcement is ample. The designer is very practical and does not try to cut corners. Strange indeed it is that the designer should have missed checking one aspect of the wind loads.

4.3.1 COMMENTS

ACI 313-77 specifically requires that the circular bending due to wind on an empty silo shall be considered. The designer has missed this. Even the commentary on ACI 313 is silent on this and provides no guidance. References 31, 32, and 33 considers this aspect for chimneys and could equally well apply to silos. All these are based on the works of Erdei, Gosh, Diver and Rumman. Considering the non uniform circumferential wind pressure distribution and resisting sinusoidal internal shear, the expressions for moments, that could cause vertical cracks on the walls, are given as $M=Kqr^2$, where $K=0.3q$ is the basic wind pressure and r is the mean radius of the silo. Since the silo is often empty at the bottom, like in the case of cement silos or homogenization silos, and perhaps empty at the top one metre, because of steel beams, these two regions are always subjected to these ring moments. At the bottom, where usually the wall thickness is more, reinforcement is on both faces and wind load is small; there are no problems. But where the wall thickness is small and reinforcement is only on one face, like in tall slender grain silos, this criterion governs and dictates larger wall thickness or two layers of steel placement. Only critical sections in the present case are at the top one metre, around beam ends, where, due to blockouts, only about 100mm thick wall exists. Since this thickness is too small, and since the reinforcement is located centrally, vertical cracks could develop in these localised zones. One should look for them after a good size wind storm. At 45m above GL, q = 125kg/m^2 and r = 9m. Therefore, the ring moment M = 0.3 x 125 x 9 x 9 = 3038 kg.m/m or kg.cm/cm. For a 10cm thick section, the tensile stress = 3038 x 6/100 = 182kg/cm^2. Permissible flexural tensile stress (ACI 318.1-83) for 280 kg/cm^2 concrete is 14.42 kg/cm^2. Increasing this value by a factor of 1.33 for the transient nature of the wind loading, gives 19kg/cm^2. Actual stress exceeds allowable stress by a factor of almost 10. Hence, cracking will be inevitable.

4.4 CALCULATIONS FOR FOUNDATIONS OF KILN BY-PASS SYSTEM

This is a well executed neat work of 50 pages. In a major project of this nature, small foundations are often half-heartedly designed and often their documentations do not exist. This is not the case with IHI. Here, even for the smallest work, the same attention is paid. Biaxil moments are also considered. There is no comment on this work.

4.5 CALCULATIONS FOR ROTARY KILN -- BLDG. AND SUPPORTS

This is an impressive work of 535 pages that could stress the patience of any designer. The same methodology is consistently followed from establishing the assumed member sizes, loading patterns, load calculations, computer analysis, bending moment and shear force diagrams, force combinations and arriving at design forces for each component of each frame to final proportioning and checking of stresses. Even the weight of grout has been considered. Nothing has been lost sight of. Equipment loads are methodically and meticulously included. Forces caused by thermal deformations of the kiln are also included. Kiln supports are isolated from the building frame. The documentation is excellent.

4.5.1 COMMENTS

ACI 318 has been faithfully followed. But the writer stongly feels that lower stresses should have been used for the beams directly under machines to account for fatigue. Although ACI 318 does not exclude such buildings from its scope categorically, it neither includes them specifically. The corresponding building codes of other countries, for instance is: 456, categorically states against its use for unusual structures with unusual loading. In the true spirit of ACI 318, some conservatism for principal beams under heavy equipment, would have been in order. While this is very true for machine-beams, it is doubly so for the kiln supports. It is more like a frame of TG foundation, where allowable stresses are reduced to almost 50%, than like a building frame where provisions of ACI 318 would justly suffice. The TG foundation design criteria in IS specifies generous haunches, minimum 25mm bars at 150 spacing on all faces, minimum 16mm stirrups -- several sets -- at 150mm even for beams, and diagonal bars same as beam top bars in the haunches. And one must not forget that the TG loads are much more controlled by much greater sophisticated means and that a TG never wobbles as a kiln could, if bent. Further, in case of TG, there are no thermal forces comparable to those of earthquake forces by its sheer momentum. Kiln supports must be designed for lower stresses. There can be no question about it.

Structural steel would be ideal material for such frames. If concrete is chosen, the load transfer mechanism should preferably be by an axial mode rather than by a flexure mode. This could have been accomplished by a wall between the columns, or better still, by the provision of a braced frame with added central column--if necessary.

ACI 315 shows corner reinforcement. This could have been followed along with a haunch. ACI 352R says that the beam-column junction will crack. This of course is a 1985 publication, but its principles are not new and have been in vogue for over five decades. Such known zones of cracking could have been better detailed.

Thermal load is included as 20° C uniform temperature rise. In fact this is not enough. Each component of the frame will be subjected to different temperatures from radiant heat. Not only that, each face of each component will have differential temperatures and gradients due to shielding effects. Moments and shears resulting from consequent deformations would be much larger. Shear deformation must also be considered.

Further, the forces resulting from the thermal movement of the base plates or frames of the machines causing lateral thrust on bolts, may add lots of unaccounted forces. Add to this the fatigue and one would see why faithful compliance with ACI 318 is not enough. And why is it dangerous. Stresses must be low. Machine supports are not buildings.

IHI is to be commended for otherwise excellent designs and documentations without which such a review would not have been possible. A final test of the design is given by the structural performance, however. Greatest compliments to a designer come from the flawless response of the structure.

IHI is at another disadvantage here. Often, when the equipment vendor and the designer are different, the vendor will supply loads after some magnification to play safe, not knowing the calibre of the designer. Here, IHI knows their designer. So, no conservatism would exist. Thus, an incidental additional safety margin that would have existed in an independent vendor-designer situation, is absent here. No one can disprove IHI's design on the grounds of calculation. But also no one can establish the cause of structural distress on the basis of calculations either. The cause is ACI 318--its irrelevance, its inapplicability.

4.6 CALCULATIONS FOR S.F. PREHEATER R/C STRUCTURES

Very thorough, methodical and comprehensive investigations of forces and stresses resulting from all conceivable sources are covered in this 155 page document. The layout of foundations -- especially the orientations -- shows a clever way to cater for lateral loads. The designer is experienced. Computer output sheets are not attached. But the bending moment and shear force diagrams are presented. This is adequate.

4.6.1 COMMENTS

If some of the beams were designed with lower stresses, it would have been a lot better. These beams should also have extra longitudinal steel on their vertical faces. Little extra, uncalculated steel may sound unscientific to a well-meaning designer but can often save a lot of trouble later on. In the days of working stress designs, when allowable stress used to be 20,000 psi in rebars and 1000 psi in 3000 psi concrete for conventional structures, the components, supporting equipment, never saw more than 600 psi in concrete and 12000 psi in steel. These structures have served well. One of the advocates of such conservatism is professor, researcher and consultant in the structural field--Mr. Dunham.

4.7 RECALCULATION TO ESTABLISH THE CAUSE OF CRACKING

Hats off to IHI. This thousand page document is a first-class work of research nature. IHI has done what many consultants would not have ventured to do. Meticulously measuring cracks, temperatures, amplitudes and frequencies at hundreds of locations and documenting them for an extended period of several months and then analysing the structures on computer and calculating manually the ultimate designed and resisting moments and shears. Their frustration and joy can both be understood. Frustration because the cause of cracks could not be established and joy because at least it must have been gratifying to know that their designers had not erred in arithmetic, at least.

4.7.1 COMMENTS

IHI's basic premise in embarking upon this monumental investigative effort rests on their firm belief that the cause of cracks can always be found analytically. Unfortunately, cracking is a complex phenomena that could be caused by any or many of the several circumstances. Who could guarantee the consistent quality of concrete and its ingredients that finally go into the structure? Work tests are only a reasonable guide. Who could ensure that the columns and the beams have the same E values? Who can find out exactly what kind of environmental impact they had? Who can vouch that the structure had precise and defined strength when forms were stricken? Who can know that the cement supplied from the same source did not have slightly different setting property? How can one know that there were no voids in some structure? How can one know that the effective depth had not varied due to changes in caver during placement of concrete? How can one know that some bar at some location did not have loose rust or grease? How can one know that the prop had not moved at some location? How can one be sure that someone inadvertently did not load the young concrete? How can one know exactly what is the stress configuration inside each member? Material and job controls are statistical phenomena, and so is ACI 318. And IHI's research proved exactly that. Out of some thousand components cast, some twenty showed distress. That can happen irrespective of calculated stresses. And let us not forget that most of them never even received the full factored load. Cracks in the beams are unfortunate but not serious. IHI should be happy that it was not a design deficiency. Shrinkage and the nightly low temperatures combined with several other factors to cause such cracks which worsened by machine vibrations. Lower allowable stresses would have gone a long way to minimising or even eliminating the cracks. If shrinkage is to be blamed, then such cracks should have been rather extensive. Stresses could be within ACI 318 bounds. This is not enough. For some components it was the wrong code--inapplicable standard--that is responsible, not the calculations.

And the cracking of the kiln supports too could have been prevented. It is by no means a building and must have been designed with reduced stresses. Other machine foundations do not show distress, not because they satisfy ACI 318 but because the stresses in them are low anyway due to large areas required by machine base out lines. Kiln supports also should have had reduced stresses. IHI should have known this. ACI does not categorically include or exclude such structures from its scope. It should be clear by implication only.

4.8 CALCULATIONS FOR OFFICE BUILDING

This document has 263 pages. It appears that some pages are missing. The index mentions "Appendix 2: Study of Differential Settlement", but it does not exist. It, however, does not matter. Having reviewed so many documents of IHI, the writer is convinced of their thoroughness. To them, all components of the structure are equally important and worthy of equal attention. This document is a fine example of applicability of ACI 318. Designs are fine. No comments.

4.9 QUALITY CONTROL PROGRAMME

This document lays down procedure for overall quality control, and includes duties of various staff members on job sites, types of reports, types of inspections, etc. It lays down the ground rules of job control. The document covers many aspects like bench marks, soil resistivity tests, cement, sand and aggregate tests, concrete tests, water, admixtures, grout and reinforcement tests, and corresponding ASTM specifications to which they would comply. ACP could not locate actual test results--there will be thousands of them -- but the writer is convinced that there was no lack of supervision and ACP confirms that no concrete test fell below the required strength. So, in this limited time, no further search need be made in this direction, especially because no signs of material weakness were found on site in actual structures.

4.10 REPAIRING PROCEDURE FOR CIVIL WORK DEFECTS

This is a short document explaining the basis, procedure and materials for repair. For hopper of limestone crusher, steel cover plates with epoxy bonding were used. For cracks in concrete larger than 0.3mm, sub-silicon was used. For grouting under base plates, when the gap was more than 0.2mm, again sub-silicon was employed. Details of the treatment procedure are described. Although the writer has no prior direct experience of these materials, it seems they have stood the test of time since mid 1984 and that is what is important. The material in cracks has remained plastic and the bond seems excellent. Aesthetics could have been considered, however. A new plant looks sick due to the lack of cosmetics.

4.11 REVIEW OF DRAWING

No attempt is made to list all the drawings that were reviewed. There are over 1000 drawings including those of roads and the drainage works. All these drawings were gone through several times to see if any incorrect detail could have contributed to the structural distress noticed. No such defects in drawings were found. Drawings are of excellent standard, well presented and accurate. Some minor comments are made.

4.11.1 COMMENTS

Diagonal bars, shown in the standard drawings at the junction of horizontal and vertical components, are missing in the case of drawings of kiln support frames. Such bars would have prevented a crack at the beam-column junction. Better still, a 300 x 300 haunch with diagonal bars would have been excellent. One staircase detail in housing drawing No. 5-07 is not as per standard detail. The lower bar at the stair-slab junction can come out. This kind of error is not repeated elsewhere. Diagonal bars could justifiably be absent in tunnels but should be present in retaining walls. If the site is expected to follow standard drawings for these bars in particular, it is not noted so, and perhaps such diagonal bars are not placed. The standard drawing shows the junction of roof beam and the block wall with a dowel from the wall into the beam. This is fine for a concrete framed building. In the case of load-bearing walls in housing areas, this would be very undesirable. In fact in that case, there should be a paper joint for the slab to slide freely to shrink. This would have been ideal and would have prevented the widespread cracking of the block walls that now exist. Even the nominal reinforcement would have helped to some extent. Reinforcement has been detailed and then has been crossed out. This was an unfortunate decision. Details of second-stage concrete around column and machine base plates should have been shown on structural drawings. In fact, the second stage concrete or mortar finish from pedestal level to the top of the base plate level is undesirable. Such concrete is cracking at all places. Around machine plates, often 100 to 300 thick second stage concrete exists. This should have reinforcement to bond with pedestal bars and a horizontal wire mesh at the top. Also, such concrete should be separated from the base plate by a flexible strip. In that case, thermal or mechanical movement of the base plate would not crack the second stage concrete. See Figs. 1 and 2.

4.12 BCEOM'S CERTIFICATES OF COMPLETION/ACCEPTANCE

Several completion certificates covering all buildings and facilities were reviewed. These were covered under BCEOM's letters, dated 29.04.82, 15.05.82, and 22.05.82. While accepting these works, a small list of outstanding items often appeared. They referred to finish items, general cleaning, small damages, small pavement cracks, etc.

No mention is found of any structural cracks or other blemishes. In fact, "concrete conditions" and "concrete strength" were always accepted without comment, and in token of their acceptance of the above two attributes of concrete, BCEOM have put their signature. This indicates that no cracks or other blemishes existed at that time, or if they did exist, they were not noticed or if noticed, they were considered acceptable. Minor shrinkage cracks have never been a criterion for delaying the acceptance certificates. It must be noted, however, that a one-man supervision from the consultant side can never do full justice to the word "inspection", and IHI supervising their own subcontractor is like IHI supervising themselves -- a standard drawbook of the turn-key contracts.

4.13 BCEOM'S REPORT OF 4.10.83.

This report summarises the cracking problem then noticed and gives reasons for each distress. Causes noted are, shock load for LS hopper and Gypsum and Sandy Clay Hoppers, vibrations for girders and shrinkage or shrinkage and temperature for the remaining ten items. The report also suggests a full study by IHI and present guidelines as to how to go about it. They do not approve of the method adopted by IHI for rectification of LS hopper cracking. Consulant's opinion on cracks may be correct at that time. Now the damage to No. 2 kiln support is alarming.

4. 14 BCEOM'S REPORT OF 22.5.84.

This report is after IHI carried out the repairs. The report notes that although the top concrete over kiln support is non-structural, it nevertheless should be crack free and durable, and refers to the agreement that promises to remove and replace the fractured concrete if the crack widths are 0.6mm or more. The time has now come to enforce such an agreement. Damage is considerably more now than what it was then.

The above two documents, seen now with the advantage of the retroactive view, appear rather mild and fail to consider the owner's right to have sound durable, crack-free, trouble-free, patchwork-free civil/structural components that should normally need no attention for decades. IHI has given a guarantee for 10 years. The consultant is right in assuming that the repair work will be covered by this. But strictly speaking, the owner should have been covered for all the defects found in these works for a period much longer than that. At least the life of the Civil Works normally considered in accounting -- 20 to 25 years -- by which time the replacement funds are generated, should have been considered for a meaningful guarantee. Even major bridges do not need major repairs in the first 25 years. Structures in ACP in its prime show problems. The client surely deserves a better deal. Healthy professionalism need not be content with meticulous following of the letter of the contract. The spirit of the contract is the life blood of professional ethics.

CHAPTER 5
DETAILED SITE SURVEY

5.0 GENERAL

All the structural components of all the buildings were inspected thoroughly. Distress or defects noticed are reported in what follows. Expression "second stage concrete" used herein implies concrete or mortar laid around the base plates, on finished concrete pedestals for steel columns or machines. The thickness of such second stage concrete will be equal to the sum of the thicknesses of the base plate and the grout underneath and would rarely exceed 100mm. This is non-structural concrete. But cracks in this second stage concrete are a defect by all means.

5.1 CEMENT LOADING BUILDING

This building has a structural steel superstructure which is sturdy, well-proportioned, and well built.. Foundations are of reinforced concrete. Concrete pedestals are in very good condition. Second stage concrete is spalling in 8 columns and three stair/platform supports. The overall structural condition is excellent.

5.2 CEMENT PACKING PLANT

This building consists of structural steel superstructure and reinforced concrete substructure. Upper floors are partly of concrete and partly of chequered plates. Structural steel is perfect in all respects. Concrete floors are flawless. Exposed faces of concrete substructure show no defects. Second stage concrete at one column is spalling. Overall, the condition of this structure is excellent.

5.3 CEMENT SILOS

Two cement silos are monumental works of excellent proportions. There are some minor small cracks of no consequence. Sofits of the openings in the silo walls and in the internal walls show sags and some small cracks. Sag is caused by sagging form work. Perhaps the props sank or slipped. Cracks could have origin in this sagging form or shrinkage. In either case, they are of no structural importance. They are non-propagating, dormant cracks. No attempt need be made to repair them. Concrete quality looks excellent as observed at a chipped edge of the beam. Equipment foundations are fine. There are a few patches where honeycombed concrete seems to have been repaired. This is no problem. The conventional form work in the lower portion of the outer faces of the silos has sagged inward, and this and form marks give a bad appearance. The form marks could have been repaired by carborundum rubbing. Out of circularity caused by the displaced form work is within the permissible tolerances as per AC1 117-81. Junction of conventional and slip forms presents distinct unevenness and could have been better controlled. Structurally, these silos are very good and should cause no concern. The roof slabs of these silos are also good.

Settlement of the silos cannot be ruled out. But the settlement will be gradual over many years. It will be a good idea to keep records of settlements of all silos. Near top one metre of the silos, where roof-supporting steel beams sit on the blockout in the silo wall, wind induced ring moments could cause structural cracks. They, however, will not pose any danger to the structure. Second stage concrete around stair pedestals is cracking. Overall, the structure is in excellent condition.

5.4 CEMENT MILL STRUCTURES

The electrical room consists of a concrete frame with infilled blocks. Both the concrete frame and the block work are in excellent condition. The ground floor shows shrinkage and settlement cracks. Upper floor concrete is fine. Second stage concrete at the stair pedestal is cracking.

Mill building is of structural steel superstructure, open on all sides. Steel work is well braced and sturdy. The footing pedestals look fine. Mill drive foundation and mill supports are in very good condition. Second stage concrete in the drive foundation and around one steel column are badly cracking. These are of no consequence. Overall, the structures are in an excellent state.

5.5 CLINKER STORAGE SILOS

These three silos are excellent structures. There are no visible shrinkage cracks but they should not cause concern, even if found. A distinct discontinuity at the junction of the slip form and the conventional form near ground level is noticeable. In one silo, a sinusoidal construction joint is seen. This is an instance of a bad pouring procedure. It perhaps represents unscheduled stoppage in concrete due to power or equipment failure. Silo roofs are fine.

Concrete in tunnel hatch opening is good. Cover to western entrance staircase has bulged concrete walls -- a case of bad form work. Cover to the eastern entrance stair well is badly damaged, probably by truck or other vehicular impact. This is repairable and poses no structural threat to other structures.

The cracks in the tunnel are of shrinkage origin and are not structurally serious. If the designer had used control joints or if the tunnel was cast in an alternate pattern, the cracks would not have been there. Some cracks have been repaired by flexible sealant from inside. Examination of the cracks from the outside is not possible. Effectiveness of the sealant penetration throughout the wall thickness is questionable. Sealing the crack from outside must be considered. Some construction/expansion joints are also leaking. They must be sealed from outside, using the same flexible compound.

The cable and water pipe tunnel has leaking joints. These must be treated from outside. These joints leak during rains. Leakage watermarks are seen inside the tunnel. If this is not sealed, it may cause electrical short circuits. Cable tunnels must not leak even if the cables are on racks and trays. This can hardly be overemphasised.

5.6 BURNER PLATFORM AND COOLER ROOM

Concrete work and block work in this area are very good. One column on the N.E. corner has suffered structural damage in that the rebar has been exposed. This affords a view of very good quality concrete work. This corner should be repaired. All machine foundations are good except the second stage concrete which shows cracks. Structural steel work above is excellent. Second stage concrete in duct supporting steel framing bases is cracking.

Kiln-Hood support concrete is badly cracked and bolts are sheared. The concrete seems to be second stage concrete but carries the Kiln-Hood. This is important and needs immediate attention. A short staircase is badly damaged, probably due to equipment impact of some sort. Damage to Kiln-Hood support seems to be from the thermal and the equipment shocks.

5.7 KILN SUPPORTS

Kiln supports No.1 has badly cracked top concrete. This has several vertical cracks and a horizontal crack. These cracks are all sealed by a flexible material. Although this looks dangerously unsafe, this is essentially a second stage concrete. Structural concrete starts about 300mm below the top. Horizontal crack is essentially a separation of this second stage concrete from the structural concrete. This second stage concrete is not shown on structural drawings. To a structural engineer the purpose of this concrete is to protect the structural concrete from the radiant heat. If the second stage concrete is important from a mechanical standpoint, it should be repaired by grouting and then jacketed in a metal sheet. Some vertical cracks have propagated into the top 200mm of the structural concrete. These are sealed by the same flexible sealant. These should be repaired by structural material and should be jacketed to provide lateral containing mechanism. Any damage to kiln support must be considered serious and must be repaired for the structural integrity.

The lower beam shows some cracks but they can be repaired by grouting with appropriate epoxy compound -- not the sealant. Columns of this support have no cracks of any structural consequence.

Kiln support No. 2 has top second stage concrete cracked in a similar fashion as that of support No.1 and can be treated in the same way. The top beam of this support is in good condition. The columns and the lower beam have several bad cracks. These cracks have advanced considerably since 1984, as can be seen by comparison with IHI's report. This support needs immediate attention.

The reason for cracks in this support, in addition to the high stresses permitted in its design, is found from the verbal reports of the operating staff. According to them, when the kiln is allowed to stand in one position for a long time, without periodic rotation during shutdown, it sags. This sagged kiln, when started, runs eccentrically and hits on the rollers with considerable force. The support shakes badly and this continues till the kiln is heated and allowed to lose the sag. This has happened several times including the time when IHI was commissioning. An eye witness said that the support was rocking with over 30mm displacements at the top. Rocking was from the foundation upward. The cracks in the soil in contact with longer outer faces of the column and along the short edges of the foundation of this support point to the truth of the observer's narrative. Severe cracking of the middle beam at beam-column junctions, and at two third-point locations, along with many cracks along the outer faces of the columns, bear witness to the earthquake-like damage.

Rectification for this support must be undertaken at the earliest. The structure may not be able to take another whip. The rectification method will be proposed elsewhere in this report. Since the cracks are advancing in this No.2 kiln support, detailed mapping of the same was carried out. These are presented in Fig. 4. The upper beam shows three vertical cracks near about the central third of the clear span on the west face. The middle beam shows two main cracks that run along west and east face and on the top and bottom -- a continuous belt. Signs of concrete having been crushed are clear on the east and the west faces. These two cracks are from 1mm to 12mm wide at places. Three cracks, which existed at the junction of this beam to the north column on the west face, are advancing. Two new cracks have developed at the junction of this beam and the south column on the west face. One crack on the north column and two cracks on the south column towards the lower half of the lower bay are also present on the west face.

The south column shows several short horizontal cracks on the east face. The middle beam has pronounced cracks at its junctions with the north and the south columns and at approximately a third to quarter points of its clear span. These are pronounced and form a continuous belt mentioned earlier. The inner and the outer faces of the south column have several cracks in the lower bay. Similar but longer cracks exist on the inner and the outer faces of the north column in the lower bay. The beam-column junction cracks are continuous over and under the middle beam, along the inner faces of both the columns.

Two horizontal cracks exist on the inner face of the north column in the upper bay, approximately 1200mm below the sofit of the top beam and 200mm above the top of the middle beam. Some poor concrete appears along this lower crack -- on the inner face of the south column. About 300mm wide belt above the middle beam shows very poor concrete. Concrete could be very easily broken in this area to reveal a timber strip 25 x 10 x 3000 long encased in it. Apparently the form work had sagged inward into the column and a patch repair was done. This is a very bad and irresponsible act of the contractor. When the timber strip was removed, a continuous horizontal crack was found concealed. Support No. 2 is so bad in fact that the operators are afraid to start the kiln after stoppage. They can hardly be blamed. Here the bad design, following wrong code, and allowing potentially dangerous stresses has combined with the bad construction and the cover-ups. Both columns have very bad concrete near (and perhaps below) the ground level, where the concrete is so bad that the rebars have already corroded. It is strange that a reputable firm like IHI permitted such bad work or tolerated JWD's "cover up" tactics. This makes one suspect if IHI really had the supervision of quality that is displayed in their documents. In any case, the contractor has been very irresponsible and has made the structure more risky. Damage can be seen in photographs.

Kiln support No. 3 has similar damage to second stage concrete as in No. 2 support, but of somewhat lesser magnitude. This can receive the same treatment as No. 2 and No. 1 supports. The structural components of this support seem crack-free except for a horizontal crack on the north side column, just below the top beam. This can be repaired by epoxy injection.

5.8 KILN DRIVE

Columns and block walls are in very sound condition. The ceiling of the first floor slab has some random cracks which are of no consequence. Beams of the floor under the Kiln Drive are cracked and have been repaired. Vertical cracks on the girders and beams and those at beam-girder junction are all of shrinkage origin and perhaps widened due to the action of the drive above. Beams otherwise look fine. Since no new cracks were noticed, the structural distress has stopped and there is no danger of any kind. Cracks in the drive foundation must need repair. Some are in the structural concrete.

5.9 AIR DUCT SUPPORT

The corners of the two north side columns have very poor quality concrete. It seems they were repaired later on. All the bad concrete must be removed and replaced by new concrete. Cracks in the beams are repaired. No new cracks were noticed. Some horizontal cracks near the bottom portion of the columns emanate from bad concrete. These may be thin but are not shrinkage cracks. They are due to the weakness in the structure. The duct supporting pedestals have bad cracks. These are caused by bad erection and perhaps by bad details. Pedestals are eccentrically loaded. The designer perhaps assumed that the base plates would be of the same width. One base plate is too close to the edge of the pedestal. The pedestals need repair. This small structure is an outstanding example of bad construction and bad planning. The columns could have been directly under the base plates. A solid block foundation would have been more economical and trouble-free. The contractor could have been less dishonest in covering up the bad concrete in the column.

5.10 MOTOR ROOM

The concrete frame and the block work are in good condition. Some cracks in the beams are repaired. No new cracks were noticed. This may be considered satisfactory for now.

5.11 S.F. PREHEATER

The concrete frame and the block work in general are good. Structural steel is excellent in the superstructure of this building and in adjoining frame work. Some concrete beams have cracked. Rectification is done. No new cracks were found. Original cracks are of shrinkage origin but worsened by equipment loads and vibrations. Reduced stresses in these beams should have been considered.

5.12 MAIN DRAFT FAN FOUNDATION

Overall concreting looks adequate. Some cracks have been sealed. This is satisfactory. But some new (or perhaps originally small) cracks on the eastern cantilevers were noticed. They are diagonal cracks, starting from the edge of the base plate. These are not shrinkage cracks. They are of shear origin. Maybe the concrete is weak inside. These cracks must be sealed by epoxy injection -- not by flexible sealant. Even supporting the cantilevers from below, by adding concrete stub columns, may be advisable.

It is not the width but the nature of these cracks that causes concern.

5.13 HOMOGENIZATION AND STORAGE SILOS

These are good, sound structures. Wall thickness is enough. Some cracks were noted in the past. No new cracks were found. These cracks are of shrinkage origin and are of no structural consequence. Fortunately, like other silos, these silos are sound. Lower parts of the silos are complex and can induce a complex shrinkage stress pattern. Small cracks are not stress cracks and need not be worried about.

5.14 RAW MATERIAL MILL

The steel structure and the concrete foundations are in very good condition. Some column bases are covered in dust. Structure should present no problems. The drive foundation shows cracks and spalls in the second stage concrete. Though this is of no structural consequence, it must be repaired or recast.

5.15 FAN FOUNDATION (ON THE SOUTH SIDE OF MILL)

This is a fine concrete work. No cracks were noticed. It would have been pleasant if other foundations were like this. Unfortunately, it is not so.

5.16 CLAY AND GYPSUM CRUSHING AREAS

There are some shrinkage cracks of no consequence. They are not active and should be no cause for alarm. But the cracks in the hopper should cause concern. Although hoppers do not fail by such cracks, definitely their durability gets reduced. Steel plate with epoxy bonding has worked well elsewhere in this plant. The same treatment should be considered for this hopper too.

5.17 RAW MATERIAL MIXING BED

The area is covered in deep dust. ACP reports that the rail supports have transverse cracks. These are of shrinkage origin. But they could be stress cracks too.

Rail and its concrete pad do not seem to have expansion joints. Expansion joints would have reduced the cracks. However, these cracks should not cause concern. The steel structure looks sound.

5.18 CONVEYOR SUPPORTS

The steel components are well proportioned. Second stage concrete at the bases is cracking in some cases. This should be treated with care. These are not big structures but are important supply links to the plant. Base plates should be protected by adequate drainage around.

5.19 LIMESTONE CRUSHING PLANT

This is a sturdy piece of structural engineering with strong, well braced steel superstructure. The concrete components are heavy and well made. Only some beams have cracked and the hopper had cracked. The writer has seen much bigger and thicker hoppers for iron ore crushing plants cracked. These giants are continuously under the heavy shelling of large blocks of rocks. No wonder they crack. Unless almost the entire hopper is directly supported on the ground, with the least lengths of overhangs -- just enough to place the conveyor underneath -- the hoppers will crack. Thick slabs with plenty of rebars -- that is very low stresses -- can largely avoid the cracks. It would be unjust to blame the designs here, though hoppers can be made to last longer. The steel plate jacket, bonded by epoxy, is a good rectification. If the bond between the concrete and the steel plate could be maintained, the hopper should last for decades.

The shrinkage of the beams is primarily due to heavy restraints they have at their ends. Most of this shrinkage could have been avoided by proper pouring sequence. This kind of pouring sequence is, however, not customary in buildings. Even in the case of TG foundations, the pours are made as continuous as practicable for other reasons. Use of a lot of reinforcement -- bringing the stresses down to half or less of the ACI 318 permissibles -- save such massive structures. The writer has never seen any shrinkage cracks in large-200mw-TG framed foundations. As long as the beams do not support vibrating, rotating masses, a crack or two are harmless. But in a beam supporting heavy machines, the cracks can grow. A flexible sealant would stretch and prevent the observation of widening cracks. They will keep gases and moisture off alright, but they do not remedy the lost structural strength. Fortunately, no new cracks were noticed and the structural integrity is not in doubt. The sealant treatment does look bad though.

5.20 **WATER TANK**

The tanks are not leaking. Small leakages are self-healing. The form joints are noticeable. Some rectification is done which is alright. The second stage concrete is fine here. Plant growth close to the concrete tanks should be discouraged. The roots of the plants, to reach the water in the tank, often secrete chemicals that break down the concrete. The roots then penetrate concrete walls with unpleasant leakages.

5.21 **BOILER HOUSE**

This small structure is O.K. Boiler foundation is fine. Package boilers never give trouble to foundations.

5.22 **POWER STATION**

The concrete work in the building and the machine foundations are good. There are minor cracks in the second stage concrete of the machine foundations at every bolt location. But no treatment is required. The block work has several bad cracks which should be rectified. Some window sills have cracked along with the block walls. New window sills, with heavier steel (or some metallic sills) should be installed. The cracked sills and the cracks in the block wall below respond to vibrations and are caused by them. The bolts on two pedestals in the basement area were found sheared some time back and are replaced now. These were perhaps deliberately cut to ease the erection of pipe supporting framing. Perhaps the bolts were set out of alignment or the steel fabrication was wrong. These bolts are not critical. Now, since they are replaced, it is all the more safe.

5.23 LABORATORY

Except for some badly cracked block walls, all else is good. This important facility is well furnished. It has a potential to venture into commercial concrete cylinder testing, besides its primary work of cement testing. It could also conduct independent research, testing local materials and this contributing to national knowhow about national building materials. If the staff is interested, ACP should consider this welcome diversification. Publication of such research papers can put YAR on the international technical scene.

5.24 COMPRESSOR HOUSE

The floor finish is peeling. Some cracks were noticed. Machine foundations are in a very good and sound condition.

5.25 OIL TANKS

The tanks look fine. Traditionally, the tank foundations are allowed to settle. One tank has gone down by 20mm. In anticipation of such settlement, the connection to piping is made flexible. This is also conventional.

5.26 HOUSING AREA

The houses present a sorry state of affairs. Those with concrete framework and in-filled block walls are in an acceptable state. But those with load bearing block walls are badly cracked. Some are so badly cracked that in the first world countries, the approving authorities would consider them unsafe. Even if they do not collapse under normal conditions, a mild jolt of earthquake may destroy them. Apart from this, they give an unsafe feeling to occupants. Exterior walls are more heavily cracked than the interior ones. Most cracks do not penetrate across the wall; the cracks are wider on the outer side in general.

The houses stand on a continuous concrete band footing, founded about a metre below grade, on virgin ground. The cracks are not due to settlement. Most are not due to shrinkage of walls. They are caused by the shrinkage of the roof slab that tends to pull the walls inward, causing horizontal cracks, and by the diaphragm-type resistance of the internal walls, causing vertical cracks. The resultant force causes diagonal cracks, especially at the corners of the openings. Most cracks are several courses below the underside of the roof beams as it should be in this case. This conclusion is amply supported by reference 31. Cracking appears to have stopped by now. The cracks have been repaired by grouting the plaster on the outer faces of the exterior walls. This rectification does not provide structural strength, nor does it restore the original integrity of the walls. The cracks on the inner faces of the exterior walls and those on the inner walls are not grouted.

The absolute minimum treatment required to make these buildings acceptable must include cutting the plaster along the cracks, grouting the cracks with mortar under pressure, plastering back using metal lath-chicken wire mesh-backing, and complete repainting on all the faces of all the walls where any cracking has occurred. If the bond between the old and the new plaster cannot be ensured or where cracks are too many, a complete replastering must be done. Plaster should be cured so that it does not crack again.

The sanitary fittings in the buildings are poor and leak after a few years infrequent and scanty use. They should be repaired or replaced. It does not need an expert to see that the contractor's performance is very poor in these buildings.

5.27 CONCRETE ROADS

Roads are acceptable, but the joint (or crack?) at the crown needs sealing in some areas. All joints must be resealed to prevent rain water from reaching the subgrade.

The roads are a very good example of what control joints could do to keep the shrinkage cracks to the minimum or to virtually eliminate them. There are very few shrinkage cracks. Good work by IHI.

5.28. BOUNDARY WALL

The boundary wall is well constructed with expansion joints provided generously at 10m or so intervals. This has been a wise step to avoid cracking and it has worked. If any crack appears, it must be rapaired by grouting.

5.29 OFFICE, CHANGE HOUSE, CANTEEN, MAINTENANCE SHOP AND WAREHOUSE

These are framed buildings with in-filled block works. Structures are fine. Here ACI 318 does not let down the designer. These are fine structures. The block walls in the canteen building are cracking badly and must be repaired.

5.30 WALKWAY SUPPORT

One structural steel walkway support near kiln support No. 2 is bent and has a cut flange. Half of the strength of the flange has gone. The leg should be straightened, the flange should be welded and a bracing member should be added here.

5.31 OTHER BUILDINGS

The buildings beyond the plant area and housing area were not visited. They include small store and magazine buildings in the mining areas. These are not included here.

CHAPTER 6
DEFECTS IN CONCRETE WORKS

6.0 GENERAL

All the concrete works in general have some defects. Some defects lead to structural weakness, some spoil the look but may not be of structural consequence. To some extent, the small defects can be tolerated. ACI 201.1R-68 pictorially describes many kinds of defects. Cracks, honey-comb, form marks, cold joints, surface holes, and bulgings are general defects found in ACP structures. Another defect found involves patch repair done to defective works. These are addressed below along with their method of repair.

6.1 CRACKS DUE TO SHRINKAGE OR VIBRATION

Most of the shrinkage cracks found are harmless. Cracks larger than 0.3mm have been repaired by IHI. Most of such cracks are now dormant and are considered of no structural consequence. Locations of such cracks are covered under IHI's survey and are generally mentioned in Chapter 5. Since these are well documented by IHI and since they are dormant, duplication of its documentation here is considered unnecessary. The only problem with the present repair method is that they look bad, patchy work, which cannot be acceptable in a new plant. Such patch repair marks could be understandable after 50 years. But not in the early years of the plant. Therefore, all such repairs must be redone using material that does not look ugly.

The cracks in the components that directly support vibrating, moving or rotating equipment, as cracks in some beams, machine foundations, and kiln supports, may be of shrinkage origin but are worsened by stress and vibrations, especially because lower stresses were not used in the design of such components. These cracks are considered of structural importance and must be repaired by epoxy injection. Of course, again, they must not spoil the look of the structure. The cracks in the kiln supports are VERY SERIOUS and must be attended to at the earliest if disaster is to be avoided. Two areas of very bad concrete -- segregation and honeycombing -- are found at the base of the columns of the kiln support. Some portion in these areas could be broken easily by a piece of stone (not a hammer). This concrete is really very bad. This should be further broken and repaired by new concrete and bonding agents. This will be addressed again elsewhere in this report. Cracks in the hopper are already attended to by IHI using steel plate and epoxy bonding which shall be considered satisfactory. The same method may be applied to non-structural concrete around the kiln support rollers, etc., for the sake of permanence. Once the present cracks are sealed by epoxy injection or by replacing old concrete by new one, the steel plate jacketing with epoxy binder will resist further cracking in future. IHI will have to verify the properties of epoxy for the temperatures to be encountered.

The cracks in the second stage concrete around the base plates are not of structural consequence in general. It is advisable to remove such concrete and alter the detail as per Fig. 1 so that the grout condition under the base plates can be always examined. If the grout thickness is more or for other reasons the second stage concrete must be level with the top of the base plates, detail of Fig. 2 shall be followed. Where the original detail is very sound, as for example in the powerhouse, it can remain. The cracks in the second stage concrete are caused by poor bond with the pedestal, thermal loads, vibrations or some combinations of these. This treatment is absolutely essential for the new look to the plant and for the durability. No client can be happy with the present state of affairs.

The cracks in the tunnels can be considered of shrinkage origin but the ones that could have been foreseen and could have been avoided by provision of control joints, spaced at about 10m, as per ACI standards. To that extent, it can be considered a detailing defect. However, since it is not visible from outside, ACP may consider it practical to accept existing treatment with flexible compound. Cracks or joints in the tunnel that leak must be repaired from the outside using the flexible epoxy treatment. A leakproof construction is absolutely essential in all the concrete works -- more so in the tunnels.

It is a well known fact that all the cracks -- especially all shrinkage cracks -- cannot be eliminated, and in the true spirit of this fact, the shrinkage cracks smaller than 0.3mm would be accepted without any treatment. Shrinkage cracks are unusually many in this project, partly because the construction sequence to reduce them was not considered and partly also because the nightly low temperature acted along with the plastic shrinkage and the drying shrinkage phenomena.

In future, if the beams show potentially wide cracks that respond to stress, other methods like stitch repair or external pre-stressing, as per ACI 224.1R, should be considered. Such methods do not seem warranted at this time and perhaps will not be necessary in future.

6.2 HONEYCOMB/SURFACE HOLES (BLOW HOLES)

Some patches of honeycomb are seen. They should be pressure-grouted only if hommening reveals poor concreting in that area. This is not suspected, but the testing with a hammer at all such areas to find weakness must be done, and where required, pressure grouting or gunniting should be used.

Surface holes are many and widespread. They appear to have weaknesses in that a light stroke of hammer often removes a lot of loose material. Extensive hammer testing must be done and where required, pressure-grouting should be carried out to eliminate the structural weakness. Such blow holes usually are unimportant but can accelerate the deterioration in the fatigue-loaded structures.

All the pressure-grouted surfaces must be rubbed with carborundum to evenly match with the surrounding surface.

6.3 FORM MARKS AND CONSTRUCTION JOINTS

These defects are mainly in the silos and Water Reservoir. They must be rubbed to even surface for proper and healthy look. Smaller areas like those of beams or columns are good.

6.4 PATCH REPAIRS

Two such areas have been noticed. One is in the columns of the kiln support No. 2 and the other is in two north columns of the duct supporting structure. These are very badly done and do not speak highly of the contractor. These are of great structural concern and must be rectified by hand packing, using bonding agents. If IHI has a better suggestion, it should be welcomed.

Although this is found in only two areas, it is suspected that more such areas may exist. A thorough search, with light hammer, is warranted to detect them. Good contractors do not resort to such tricks, involving structural risks.

6.5 OTHER DEFECTS

Due to time constraint and inaccessibility of certain areas in a running plant, the writer has not been able to look for all potentially weak spots. It is suggested that IHI should look for them and rectify them in the name of professionalism and for the safety and durability of the structures. Since the attitude of IHI's subcontractor seems to be of "covering-up the defects somehow before the inspector catches it", it is doubly important that such cover-ups be revealed and repaired. It is indeed strange and regretable that IHI allowed such cover-ups in the first place. The writer is sure that if the inspector was present when the forms were stricken, these defects could not have gone unnoticed.

The major distress noticed in the kiln support No. 2 has resulted from the higher stresses allowed in the design, operational errors and fatigue. The fatigue nature is clear from the fact that small hair cracks have started at all surface blemishes like blow holes or the snap tie plugs. This needs strengthening by addition of bracings as shown in Fig 5. If the stresses in the beams are to be reduced further, an introduction of a central column, in addition to the bracings in Fig. 5, should be considered.

CHAPTER 7
DEFECTS IN BLOCK WORK

7.0 GENERAL

The cracking of the block work in this plant is unfortunate, ugly and widespread. This chapter examines the causes, the effects and the cures of these failure phenomena. It must be mentioned that cracks in most in-filled block works are not of structural consequence but they are failures all the same. They do give the impression of an unsafe situation to the uninitiated in the field of structural engineering. Failures in load-bearing block works must be of greater concern.

7.1 CAUSES OF CRACKS IN IN-FILLED BLOCKS

Most of these cracks are of shrinkage origin. Some appear to be due to uneven settlement. Those near the columns might be due to column settling more than adjacent structural support. Shrinkage in block works can show anywhere. Horizontal cracks due to shrinkage are unlikely. They normally follow an inclined, often stepped, course. The corners of the openings -- windows for instance -- are points of weakness. So, the cracks often start from these. Mortar is usually far stronger than the concrete of the blocks. So, theoretically, there should be no cracks along the mortar joint. But mortar also shrinks and if the bond between the mortar and the block is not proper, then the crack will follow the joints. If the shrinkage force-pattern finds a weakness in the blocks, the crack could pass through the blocks. Cracks at the joint should be considered bad workmanship. Those through the blocks are due to weakness in blocks - bad blocks.

In most developing countries, the demand for any product is more than the supply. It is true of blocks as well. Often the block manufacturers do not allow enough time to cure, or the steam curing process has temporary problems. Blocks produced during such troubled hours are also sold. Contractors too often do not inspect the blocks thoroughly. Mortar of block work is also not well controlled. Everyone at every stage fails to pay attention to block works it deserves. Block works are rarely cured. As a result they crack more than occasional cracks demanded by shrinkage. All cracks, except some thin, nominal random ones, must be considered material or workmanship failures. And must be repaired.

7.2 CAUSES OF CRACKS IN LOAD-BEARING BLOCK WORK (HOUSING)

The first impression this widespread cracking arouses in the mind is of regret. These simple structures could have been virtually flawless. Walls are short and should not have been affected by the shrinkage effect so much. These cracks are not due to shrinkage for sure. Some might have their origins in shrinkage but might have been worsened by other effects. Most cracks have an origin other than in shrinkage. It is true, as in the case of in-filled block works, that a better quality block, a better quality mortar and better workmanship and curing would have avoided some cracks. But most cracks would still have existed. It must be noted that most cracks are horizontal, some are vertical and a few are diagonal or stepped. These cracks are not due to settlement. The continuous concrete footing rests on virgin ground and is almost uniformly loaded with very light loads -- the dead loads of the blocks and the roof. There cannot be any significant settlement - much less the uneven one under such loadings.

The cause of cracking in walls lies in the shrinkage of the roof slab. Since the bond between the wall top and the slab (or beam) bottom is not broken by appropriate separation joint, the shrinking roof slab drags all external walls inward. As a result, all external walls are heavily cracked horizontally, with cracks wider on the outer faces than on the inner faces. While a wall is pulled inward by the shrinking slab, its inward motion is resisted by the other outer or inner walls perpendicular to it. This causes vertical cracks. Since all outer walls have one or more perpendicular walls, all walls have both horizontal as well as vertical cracks. Resultant of these, horizontal and vertical stressing is often seen as diagonal cracks around corners of the openings -- doors, windows, etc. The inner walls are much less affected. A quote from reference 31 will be enlightening: "Horizontal cracks have been observed in numerous load-bearing masonry walls supporting reinforced concrete slabs. Such cracking is generally attributed to thermal expansion (contraction in present case of housing), curling or horizontal shrinkage of the slab. If the movement of the slab pulls the top of the wall sideways, the wall usually cracks several courses below the underside of the slab....Therefore, it is important to break the bond between the wall and the slab by positive means. A typical method of breaking such a bond is shown in Fig. 3." Fig. 3 refers to a figure in this report.

Thus, in case of housing there is no doubt it is the detailing error that has led to severe cracking. A nominal vertical and horizontal reinforcement would have helped a great deal in the reduction of cracks. Reinforcement is detailed on the drawing but has been crossed out. This economy too has contributed to ugly cracking. Seismic performance of unreinforced block wall is always questionable -- more so in cracked masonry, even after the repair.

7.3 REPAIRING THE CRACKS

To repair the cracks the plaster shall be removed at least 75mm on either side of and along the cracks. Mortar or epoxy mortar should be filled in the cracks very carefully by hand trowel or better by gun for proper penetration. If this is not done properly, not only the seismic or wind resistance of the walls will be lost, but also the vertical bearing capacity shall be reduced. After the crack-mortar is cured, the strip shall be replastered using chicken wire mesh backing. In view of the widespread cracking on the housing units, the entire replastering of the outer faces of the walls with the said wire mesh should be considered. The exterior (and where repair is done on the inside, the interior) surfaces shall be completely repainted to avoid the patchwork look. Present buildings with excessive cracking shall be considered structurally unsafe without the thorough repairs.

CHAPTER 8
CONCLUSIONS

8.0 GENERAL

From the foregoing chapters, the following conclusions are drawn. The sequence of items may differ for logical order. Corresponding recommendations are contained in the next chapter. These conclusions recognise one main central fact and it is that the personnel in a running production plant have strict schedules and targets to meet. They cannot be expected to indulge in research type of activities in measuring cracks and logging them. But as a part of general maintenance, a watch on certain areas may be kept so that the surprises are avoided. This is as true of structures as it is of machines. Prevention is always better than the cure and a timely cure is better than a delayed one.

8.1 SOIL

The plant rests on clayey soil. Bearing capacities assumed are rather high on the basis of N values and theoretical relations. Laboratory confirmations were voided and no confirmatory load test was performed at the site. Shear failures are unlikely but settlements over a long period should be expected. The heavy oil tank has settled 20mm already. Lower bearing capacities should have been used for machine foundations.

8.2 NATURAL FORCES

Wind loads assumed seems adequate. No structure will collapse in wind storms. Most structural designs are not governed by wind or earthquake since 33% overstress is allowed. The world map of earthquake epicentres shows quite a few moderate to heavy earthquakes having their epicentres around the Red Sea. Amran area is stable. But even the world's most stable areas get an occasional heavy shock. Structures here are designed for low earthquakes. They could have been made resistant to moderate shocks by slightly more steel in stirrups. Concepts of post earthquake importance are applied to hospitals, water supplies, etc. -- the essential services that should survive the disaster so that they could serve those who suffered. Owners of cement plants can argue that their industry is useful in reconstruction of earthquake-destroyed buildings and other facilities and hence are of post-earthquake importance. The probability of a heavy earthquake or even a moderate earthquake has been assumed to be very small at the ACP site. The designs are consistent with such an assumption. The basis of this assumption does not seem to have been documented.

8.3 LIVE LOADS

Live loads considered in the design of this plant and ancillaries are adequate. Some may never be realised.

8.4 CODES AND STANDARDS

ACI 318 and A.I.S.C., the two basic standards of international recognition, are followed in the design and construction. This should be adequate in most cases. But ACI 318 is a building code. As it does not apply to bridges, as it does not apply to nuclear plants, as it does not apply to chimneys and silos fully, so also it does not apply to machine foundations and machine supports. ACI 318 does not include or exclude them categorically. But by logical implication, it should be clear. Conservatism advocated by codes for TG foundations and by the authorities all over the world regarding allowable stresses should have been followed in components carrying machines. Since this is not done, some distresses should be expected.

8.5 PLANT LAYOUT

Plant layout is excellent. It has not overlooked the prevailing wind direction. Spaces around the equipment and clearances around electrical panels are ample. The writer has seen badly laid out facilities elsewhere. IHI deserves commendations.

8.6 DESIGNS, DETAILINGS, DRAWINGS AND DOCUMENTATIONS

Designs are excellent, meticulous and methodical. Details are practical, drafting standard is very good and documentation is superb. The only other place the writer has seen such documentation is in the field of nuclear plants. IHI could be proud of it. A small amount of diagonal bars at member intersections and occasional haunches would have made detailing perfect.

8.7 CRACKS IN SILOS

Do not worry about them. This is not a problem. The silos are strong and durable. Lower level form work could have been better. Thin wall thickness at roof level around steel beam ends could have been thicker. But perhaps the wind load distribution in the proximity of the roof may not be conducive to apprehended ring moments. All looks well in general.

8.8 CRACKS IN SECOND STAGE CONCRETE (GROUT)

This is not a structural problem. Cracks look bad and give the feeling of something being weak. There is nc danger to equipment or structure. But this unwanted concrete could have been avoided in all steel column bases and in most machine bases. The detail is bad (see Figs. 1 and 2). Loss of grout from under the bases of structures or machines can be serious and deserves attention.

8.9 CRACKS IN TUNNELS

Transverse cracks in tunnels are really relief joints. They could have been planned as control joints. Sealing the cracks or joints from inside is not enough. Some joints and cracks are leaking already. They must be sealed from outside. Looks or appearance is of no importance here. The joints must not leak. The sealant must perform. That is important.

8.10 CRACKS IN BEAMS

All cracks have their origin in shrinkage but some are worsened by equipment vibration. Fortunately, they are now dormant and unlikely to grow. No new cracks have developed in the past two years. Repair looks bad. Something needs to be done. Structural integrity is not affected. In some cases, like for a girder spanning between massive columns or for a beam spanning between two massive girders, such cracks could have been foreseen and avoided by judicious sequence of pouring as it is routinely done in the case of bridges.

8.11 CRACKS IN LS EOPPER

This is a standard problem in most heavy crushing plants. This is no more a problem now. The rectification done by IHI should last for a long time. Usually hoppers are constructed to last at least 25 years. LS hoppers may last that long.

8.12 CRACKS IN ALL IN-FILLED BLOCK WALLS

. These cracks are non-structural in the case of non-load bearing walls. They look bad. They must be repaired. These could have been avoided by proper curing during construction and by using properly cured blocks.

8.13 CRACKS IN HOUSING BLOCK WORK

Most of these in themselves are not shrinkage cracks. They are due to shrinkage of the roof slabs. A lot of them could have been avoided by providing a paper joint under the roof beam and over the wall top. They are repairable and unlikely to form again. These are detailing failures.

8.14 CRACKS IN SECOND STAGE CONCRETE OVER KILN SUPPORTS

These are caused by thermal movement of steel work they encase. Structurally, the concrete has no utility. If it has any function for mechanical discipline, they must be repaired/recast and contained by steel plate jacketing.

8.15 CRACKS IN KILN SUPPORTS

Support No.1 and No. 3 do not have much problem. Cracks in them, if developed, can be repaired. But the cracks in No. 2 support are many and active. They are not shrinkage cracks. They are structural stress cracks. Support is very weak and must be repaired and modified. See Fig. 5. Bad concrete areas must be made good.

8.16 SUMMARY

Table 2 summarises the problems in the structures of ACP, their causes, and states if the treatment in each case is required. This summary is a convenient reference only and it does not deal with all the relevant details.

TABLE 2

Components and Defects	DEFECTS DUE TO					Effect on Strength	Treat-ment Reqd.
	Design	Detail	Const.	Inspe-ction	Temp. Shrink Vibra.		
Cracks in Silos	✓	-	✓	✓	✓	None	None
Cracks in P[illegible]s not carrying E[illegible]ipment	-	-	✓	✓	✓	None	None
Non-leaking Cracks in Tunnels	-	✓	-	✓	✓	None	None
Leaking Cracks or Joints in Tunnels	-	✓	✓	✓	✓	Some	Yes
Cracks in in-filled Block Works	-	-	✓	✓	✓	Some	Yes
Cracks in Beams carrying Equipment	✓	-	✓	✓	✓	Some	Yes
Cracks in Second Stage Concrete	-	✓	✓	✓	✓	Some	Yes
Cracks in Hoppers	✓	-	-	-	✓	Much	Yes
Cracks in Kiln Support No 1 and 3	✓	✓	-	-	✓	Much	Yes
Cracks in Kiln Support No. 2	✓	✓	-	-	-	Very Serious	Yes
Bad Conc. and Cover-up in Kiln Support No. 2 and Duct Support	-	-	✓	✓	-	Very Serious	Yes
Cracks in Block Works of Villas.	✓	✓	✓	✓	✓	Very Serious	Yes
Cut/bent Steel Leg in Walkway Support.	-	-	✓	✓	-	Very Serious	Yes

CHAPTER 9
RECOMMENDATIONS

9.0 GENERAL

As far as possible, the items in this chapter follow those in the conclusion. The basic premises of this report in general and the recommendations in particular, are that this is a technical and factual report. It does not directly talk about the responsibility of the contractor or others, nor by implications it intends to indulge in judicial or contractual matter. The consultant may do that. However, a common norm in the civil/structural field is that the owner must get a sound, new, good looking, structure that is durable and reasonably maintenance-free. In most such contracts the owner is within his rights to expect and demand a structure that is well designed, well built and does not give a sick look. Most concrete structures last a lifetime without any maintenance, except painting. In accounting, often the life of the structures is assumed to be twenty years, that is a 5% depreciation annually, and funds are set aside for major repairs after twenty years. Actually, the structures last for over a hundred years with routine maintenance. So, if the structure shows distress and needs repairs or looks sick in its early years, the contractor should be concerned about his bad publicity, irrespective of the conditions of contract or the financial obligations.

It is often easy for the contractor to blame the operation staff for the structural distress. But it must be emphasized that the structural engineer is expected to know the usual and normal malfunctions in the machines that he intends to support and must foresee and cater for the forces resulting from them. Accuracy of calculations or following a particular code does not necessarily imply the applicability of the code. In special and unusual structures, other relevant codes, standards, criteria, recommendations of authorities, and usual practices of the professionals in the relevant fields, MUST be followed. Failure to do so implies violations of codes and practices not consulted; besides the unpardonable technical ignorance.

Anyone designing structures for the third world must additionally know that operation staff may be new and may make mistakes. Normal incidental lack of judgement by a new hand must not result in destruction of a structure or for that matter of the equipment. If the equipment remains functional after an operational error, but the structure shows distress, then the equipment design is good and the structural design is poor. Further, from the intimate knowledge of the third world countries, the writer can say with confidence that the operations staff in these countries may not always have the qualifications similar to their counterparts in the first world, but they usually are excellent craftsmen and technicians and handle their machines with responsibility and due care. After all, they are trained by the first world.

The following recommendations are made in the above context and in the light of the professional spirit and competence always shown by the first world who trains the operations staff.

9.1 SOIL

High bearing capacity derived from N values, without the due corroboration of plate-bearing tests, should be considered a fundamental violation of good practice. If piles were used, a pile load test -- perhaps several pile load tests -- would have been done. So, at least a few plate-bearing tests would have been in order. ACP should keep a watch on settlements of all the structures. Keep a mark on one structure in each facility and take levels at least twice a year and keep records. Provide drainage away from all the structures and keep the surrounding area clean for drainage. Clays are strong when dry but weak when wet. Avoid water going into foundations. This will avoid the possibility of serious differential settlement. Watch the temperatures of the bearing of the machines. Increased temperature may be due to mechanical misalignment or due to uneven settlement.

9.2 NATURAL FORCES

Do not store light objects on roofs. They could fly in the wind and could land on someone or some equipment with unpleasant consequences.

9.3 LIVE LOADS

Flat roofs are designed for small live loads. Do not store heavy material or objects on roofs. A 100mm water accumulation on roofs due to clogged drains can be dangerous. Keep roof drains clean. Removal of leaves, rags, paper, or plastic bags from the roofs periodically is a must. They can clog the drains and load the roofs.

9.4 CODES AND STANDARDS

ACI 318 does not apply to equipment supporting beams, machine foundations and kiln supports. Keep a record of any distress on these structures. By beam here is meant not all beams, but only those which are directly under equipment. These are all designed for ACI 318 stresses which are too high for them. Distress is to be expected. Do not worry about cracks in other beams. Fatigue failures in concrete (literature says) are not reported. That does not mean they cannot happen. Concrete is never highly stressed in the fatigue-prone structures in the first place. Machine supports cannot be designed with ACI 318 allowable stresses. Stresses are too high.

9.5 PLANT LAYOUT

You have an excellent plant layout. Do not store unwanted material in the plant area. They could create obstructions to well-meaning operation staff and can lead to accidents. Keep the staircases, walkways and tunnels clean of spilled material. Obstructed passages discourage maintenance and supervisory staff from visiting those places with consequent neglect of the routine checks and maintenance. They may lead to accidents.

9.6 DESIGNS, DRAWINGS, DETAILING AND DOCUMENTATIONS

Keep all documents well preserved and easily retrievable. They are excellent records and will be invaluable in maintenance, extensions, modifications and claims, if any.

9.7 CRACKS IN SILOS

Do not worry about these cracks. They are shrinkage cracks and are no threat to structural safety, integrity or durability. Blemishes like form marks, construction joints, etc. must be removed by rubbing carborundum or otherwise. IHI may not hesitate to do this cosmetic treatment as these excellent monuments are good advertising for them.

9.8 CRACKS IN SECOND STAGE CONCRETE (GROUT)

Remove unwanted second stage concrete from around the base plates of columns or machines that vibrate and from around those that do not vibrate but still show signs of cracking and spalling. They look sick. Grout under the base plates where grout has shrunk. Grout must fill the underside of the plates completely if distress to structures below is to be avoided. A shrunk grout causes stress concentrations. Adopt the detail of Fig. 1 or Fig. 2. The present detail is bad because it prevents the grout condition under base plates from being inspected, can lead water under base plates or in any case it cracks and spalls.

Around major equipment foundations, where second stage concrete is cracking, remove the present concrete up to crack depth and lay new concrete with a bonding agent, wire mesh and flexible strip as per Fig. 2. All crack repairs done at present have no strength value and they look bad. All crack repair in the case of minor cracks may be done by injection through drilled holes of a two-component epoxy that is self bonding and produces one hundred percent solid, modified epoxy resin. This must have cement colour if exposed. Such products are available (see ref. 29). Absence of grout under machine bases can lead to unusual vibration and wear of bearings. Watch out for them.

9.9 CRACKS IN TUNNELS

This is caused by the detailing defect. As per ACI, control joints at 10m spacing should have been provided. Since the designer did not, nature did. This is of no structural consequence. But some cracks and joints are leaking. They must be repaired from the outside. This is a must. Even if the cracks sealed from inside are not leaking, they may still be allowing the water to enter into the wall (may not enter inside tunnel). So the cracks should be repaired from outside. Evidence of water entering into the wall may be found later when the reinforcement rusts and causes concrete to crack and spall from around the crack. It may be too late then. So, the cracks must be repaired from outside now.

9.10 CRACKS IN BEAMS (NOT DIRECTLY SUPPORTING EQUIPMENT)

These cracks are of no structural consequence. The present repair gives a sick look. The flexible sealant must have colour of concrete. Cracks must be re-treated in this light. These are shrinkage cracks and could have been avoided by adopting correct pouring sequence in some cases. Anyway, the sick look must go.

9.11 CRACKS IN LS HOPPER AND GYPSUM HOPPER

These cracks are caused by impact. They are normal in such hoppers. The present treatment -- steel plate with epoxy bonding -- should last for a long time -- maybe the next ten to fifteen years. When the time of reconstructing the hopper comes, stockpile the crushed limestone for two months requirement. Then reconstruct the hopper and allow it to cure for 30 days or more before it is recommissioned. Crack in gypsum hopper should be treated similarly with the steel plate and the epoxy bonding.

9.12 CRACKS IN ALL IN-FILLED BLOCK WALLS

These cracks are shrinkage cracks and are of no structural consequence. Remove the plaster along the crack. Fill the crack by mortar -- by gun. Let it dry. Then redo the plaster with chickenwire mesh backing.

9.13 CRACKS IN HOUSING BLOCK WORK

These are not shrinkage cracks. They could have been largely avoided by a suitable arrangement for roof slabs to shrink freely. They can be repaired now same way as in case 9.12 above.

9.14 CRACKS IN SECOND STAGE CONCRETE OVER KILN SUPPORTS

These are caused by thermal movement of steel work encased. The concrete should be recast with proper reinforcement. Alternatively, the same kind of epoxy treatment mentioned in 9.8 should be done if the epoxy is ensured to be unaffected by the temperature. Also, a steel plate bonding, similar to that in the hopper, could be considered. In any case, the crack repairs look ugly and cannot be acceptable as they are now.

9.15 CRACKS IN KILN SUPPORTS

Supports No. 1 and No. 3 have minor cracks. They should be treated for structural strength and integrity by epoxy injection mentioned in 9.8. Repair must not give an ugly appearance. All the three supports are structurally over-stressed. ACI 318 is not at all applicable here insofar as the permissible stresses are concerned. They are not showing much distress now but they will. So they should be reinforced. Some modification of the method suggested for support No. 2 below should be considered for No. 1 and No. 3 supports also.

No. 2 support is structurally critical. It must be reinforced. Method shown in Fig. 5 is strongly recommended. This will largely eliminate the bending stresses in columns. Details can be worked out by IHI and reviewed by the consultant. In principal, a braced portal must be created. If this is not done right away, collapse could occur. No one should take chances with it. It is a design defect and a serious one, and must be attended at the earliest. This cannot be over-emphasised. All the present cracks must be treated by epoxy injection in the same way as in 9.8 before the bracing is installed. All the rectification should be done after stress-relieving the support by jacking up the kiln. This is very important. If IHI or the consultant has any better suggestions, they should be welcomed. The main point is that this support, and preferably the other two also, must carry lower stresses. If the rectification is done without jacking up the kiln, then the present high stresses in the support will be locked in and the new structure, after rectification, will be having essentially the same stresses as now. Only it will not be subjected to new bending stresses. Existing bending and axial stresses MUST be removed by jacking up the kiln.

9.16 ON TURN-KEY CONTRACTS

In most turn-key contracts in the third world the quality of the civil works suffers. Usually the turn-key contractor is an equipment manufacturer. He is not a structural engineer. He may often fail to follow the correct code. He usually subcontracts all the civil works and supervises them. A general contractor supervising his own subcontractor is equivalent to a general contractor supervising himself. One man consultant supervision is never adequate. So, the structures suffer. Bad workmanship is covered up and shows serious distress at a later date.

Repairs of structures are very difficult unless a plant is shut down for months and equipment is removed. Even then, the desirable integrity can rarely be achieved. Rectifications look patchy and give a sick look to a new plant.

The better approach is to have the consultant design all the structures, employ a civil contractor to do the construction and have the consultant supervise the construction. This will be independent and unbiased supervision.

Often the general contractors and the consultants of the first world do not deploy their best staff to do the third world jobs. They need their best staff to look after the works in their own countries where regulatory authorities are strict and competitions are keen. The alternative is for for the client to employ his own supervisory staff who are knowledgable in their respective fields. Such expert staff could be hired for a fixed period to review the works of both the consultants and the general contractors. This has been tried out in some projects and has given extremely good results. After all, staff you hire will be loyal to you and safeguard your interests. If you want good work, you will have to supervise. Self help is the best help.

This piece of advice comes from those who had interaction with the third world projects and the writer fully agrees with it. Remarks made here are general and have nothing to do with a particular project or a particular party. It definitely does not intend to imply any intentional unprofessionalism in the ACP project.

Merits of the turn-key contracts are usually explained to the prospective third world clients in terms of less claims, etc. These are usually unfounded. The other alternatives have given better results. The turn-key contracts are better only than the government to government contract. The best way for the client is to retain the technical control of the project and ensure that the technology transfer is effected.

10
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REFERENCES

Contemplating the non-availability of technical literature in YAR, the writer had carried voluminous reference material. The following references were used in formulating technical comments and solutions. Reference numbers are not marked in the text, but should be obvious from the context to one familiar with the field.

11.1 ACI 301-84 Specifications for Structural Concrete for Buildings.

11.2 ACI 315-80 Details and Detailing of Concrete Reinforcement.

11.3 ACI 318-83 Building Code Requirements for Reinforced Concrete.

11.4 ACI 318-83 Commentary on the above.

11.5 ACI 332R-84 Guide to Residential Concrete Construction.

11.6 ACI 352R-85 Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures.

11.7 ACI 117-81 Standard Tolerances for Concrete Construction and Materials.

11.8 ACI 503R-80 Use of Epoxy Compounds with Concrete.

11.9 ACI 503.2-79 Standard Specification for Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive.

11.10 ACI 503.4-79 Standard Specification for Repairing Concrete with Epoxy Mortars.

11.11 ACI 504R-77 Guide to Joint Sealants for Concrete Structures.

11.12 ACI 504.1R082 State of the Art Report on Sealing Joints in Tunnels.

11.13 ACI 531-79 Building Code Requirement for Concrete Masonry Structures.

11.14 ACI 531-79 Commentary on the Above.

11.15	ACI 531.1-76	Specification for Concrete Masonry Construction.
11.16	ACI 224R-80	Control of Cracking in Concrete Structures.
11.17	ACI 224.1R-84	Causes, Evaluation, and Repair of Cracks in Concrete Structures.
11.18	ACI 313-77	Recommended Practice for Design and Construction of Concrete Bins, Silos, and Bunkers for Storing Granular Materials.
11.18A	ACI 313-77	Commentary on the above.
11.19	ACI 350R-83	Concrete Sanitary Engineering Structures.
11.20	ACI 214-77	Recommended Practice for Evaluation of Strength Test Results.
11.21	ACI 302.1R-80	Guide for Concrete Floor and Slab Construction.
11.22	ACI 305R-77	Hot Weather Concreting.
11.23	ACI 306R-78	Cold Weather Concreting.
11.24	ACI 308-81	Standard Practice for Curing Concrete.
11.25	ACI 304-72	Standard Practice for Consolidation of Concrete.
11.26	ACI 201.2R-77	Guide tc Durable Concrete.
11.27	ACI 201.1R-68	Guide for Making a Condition Survey of Concrete in Service.
11.28	ACI 215R-74	Consideration for Design of Concrete Structures Subjected to Fatigue Loading.
11.29		Concrete Problems, Causes, and Cures by John C. Repke, McGraw-Hill Book Company, New York.
11.30		Structural and Foundation Failures by Le Partner and Johnson, McGraw-Hill Book Company, New York.
11.31		Handbook of Concrete Engineering, 2nd Edition, ed. M. Fintel, Van Nostrand Reinhold Co., New York.
11.32		Lower-Bounds for Thickness of Reinforced Concrete Stack Shells, P.C Dave, ISI Bulletin, Vol.27, Nov., 1975.

11.33 Is: 4998 (Part I) Reinforced Concrete Chimney Design Standard.

11.34 Planning Industrial Structures, by Dunham.

UNITED NATIONS

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO

JOB DESCRIPTION

SI/YEM/86/801 - 11-51 - 32.1.K

Post title Civil Structural Engineer specialized in Concrete Structures

Duration One month

Date required As soon as possible

Duty station Yemen, Amran Cement Plant

Purpose of project To assist the Yemen Ministry of Economy and Industries (MOEI), the Yemen Corporation for Cement Industry and Marketing in terms of investigating, studying and advising on the defects seen in civil works of the Amran Cement Plant and in other buildings in connection with the plant.

Duties:

1. Visit the Amran Cement Plant and inspect the whole civil-structural works of the factory, e.g. columns, beams, slabs, walls, silos, and all other structural members, which are reinforced concrete as a whole to find out the behaviour and loading conditions of each member.

2. Go through the whole structure in detail and inspect the cracks (some of the cracks are grouted and covered with cement mortar mastics), deflection or any defects being seen, sort out and list them in terms of various types of cracks and conditions of major and dangerous ones.

3. Inspect the executional drawings, job drawings,as built drawings and any other sketch related to the execution of structure prepared by the contractor and approved by the consultant, compare them as a whole with the existing situation in terms of cross-section dimensions of members, thicknesses, spans, etc.

4. Inspect the concrete laboratory test result sheets, which have been carried out periodically during pouring concrete in various stages (7 day and 28 day compressive strength), other technical characteristics of concrete, like cement tests, slump tests, aggregate gradation curves, soundness of aggregate, chemical properties of gravel, water and cement, used in concrete, and any other test results. Compare these results with the technical specifications and codes mentioned in contract documents.

5. Check the structural design and analyses to find out if the calculations and drawings prepared are according to the regulations of any approved and acceptable code, specially those which were present during construction of the factory. Ask for removal of some mastics covered the cracks and measure the crack widths, after comparison of the crack condition with those measured and listed by the contractor, make an assessment about the propagation of the cracks. Find out whether the cracks are due to concrete properties or because of structural behaviour of members.

6. Carry out necessary non-destructive/core sample tests to find out the existing average strengthof concrete applied in the structure with the help of foreign authorized laboratories, require chemical tests carried out on aggregates, extract representative to investigate the suitability of the concrete contents especially the aggregates and the alkaline content and make assessment about the average existing situation.

7. After carrying out all above mentioned inspections and studies and also any other study which the expert himself wishes to do, an overall assessment in regard to the strength, safety, durability of the structure of the factory should be done.

8. The expert is expected to prepare a final technical report, where he will indicate all his observations, conclusions and a set of recommendations. These should be formulated in such a way that will clarify the existing safety conditions and strength and durability of the structure.

9. The expert is also expected to mention his assessment and opinion concerning checking the design, drawing and contractor's recommendations and whether cracks are repairable or not, and whether these repairs will increase the safety and durability of the structure.

Qualifications: Advanced university degree (MSc. or Ph.D.) in civil-structural engineering with specialization in concrete structures, design and analysis. Minimum of 10 years of extensive experience in concrete technology and design of structures.

Language: English

Background Information:

The Amran Cement Plant started its production in the year 1982. This plant is in the Yemen Arab Republic in the Amran Area, about 50 kms northwest of Sana'a. The Plant has a capacity of 500,000 tons/year and is a modern plant.

The civil structural works of the plant were constructed by a Japanese contracting company (Ishikawajima Harima Heavy Industries Co. Ltd., IHI).

The Amran Cement Factory is facing the problem of the cracks met within the concrete structure, i.e. the doubt whether the structure of the factory which is in reinforced concrete is safe enough or not. Many cracks (various types) have been detected in the concrete surfaces of structure members, many of them are propagating. There are many questions to be answered, such as what are the reasons of these cracks, to what extent is the structure of the factory safe, is it alreav in dangerous state, what are the durability cirteria, will any repair or restoration of the cracks ensure the safety or increase the strength and durability of the structure? Are these cracks due to design, or construction materials? Or other reasons, and many other questions which are related to this particular problem.

Meetings and discussions were held between the Government, the Ministry of Economy and Industries (MOEI), the consultant, the Bureau Central D'Etudes pour les Equipements d'Outre Mer (BECOM) and the contractor Ishimawajima Harima Heavy Industries Co.Ltd. (IHI) and a UNIDO cement expert, but no direct reason relating to the origin of these cracks and its propagation could be found.

It is desirable in order to relax these problems for MOEI, and give guidance and recommendations, relating to the cracks and contingent displacements of structure components that an experienced civil structural specialist visits the factory and carries out the necessary investigations and studies to be able to give concrete and clear reasons for these defects, and also suggest whether the defected structure is repairable.

APPENDIX B
ABBREVIATIONS

ACI	American Concrete Institute.
ACP	Amran Cement Plant
BCEOM	Bureau Central d'Etudes pour les Equipments d'Outre Mer.
B.H.	Borehole
CPO	Central Planning Organisation.
EL	Elevation.
IHI	Ishikawajima-Harima Heavy Industries Co. Ltd.
IS	Indian Standard.
JWD	Jung-Woo Development Co. Ltd.
LS	Limestone.
MOEI	Ministry of Economy and Industry.
MPW	Ministry of Public Works.
MSL	Mean Sea Level.
R/C	Reinforced Concrete.
RM	Raw Materials.
RSI	Full name not known.
SPT	Standard Penetration Test.
UNDP	United Nations Development Projects.
UNIDO	United Nations Development Organisations.
YAR	Yemen Arab Republic.
YCC	Yemen Corporation for Cement Industry and Marketing.

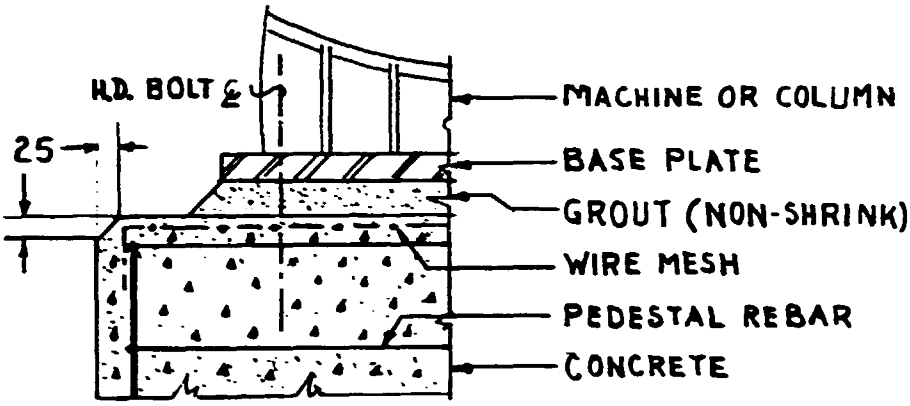

FIG. 1 GOOD BASE DET. NO SECOND STAGE CONC.

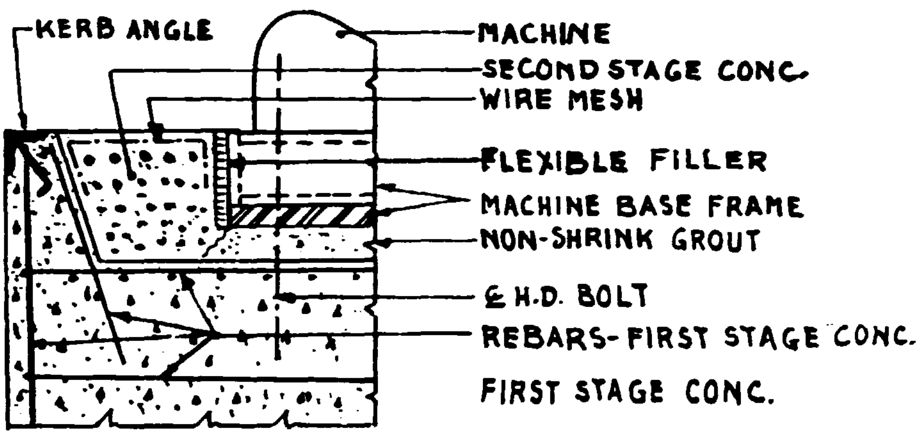

FIG. 2 GOOD BASE DET. WITH SECOND STAGE CONC.

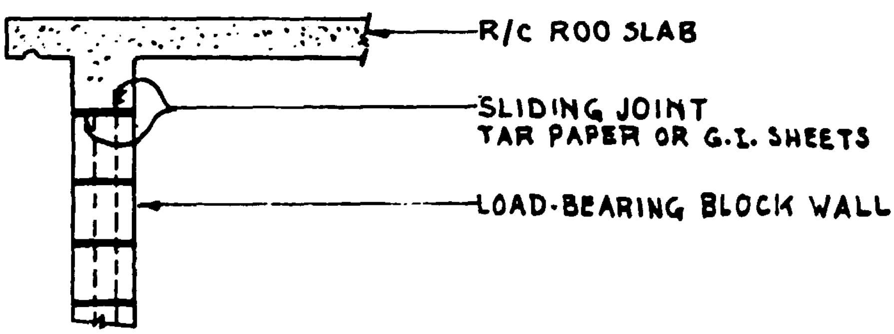

FIG. 3 SEPARATION JOINT AT TOP OF BLOCK WALL

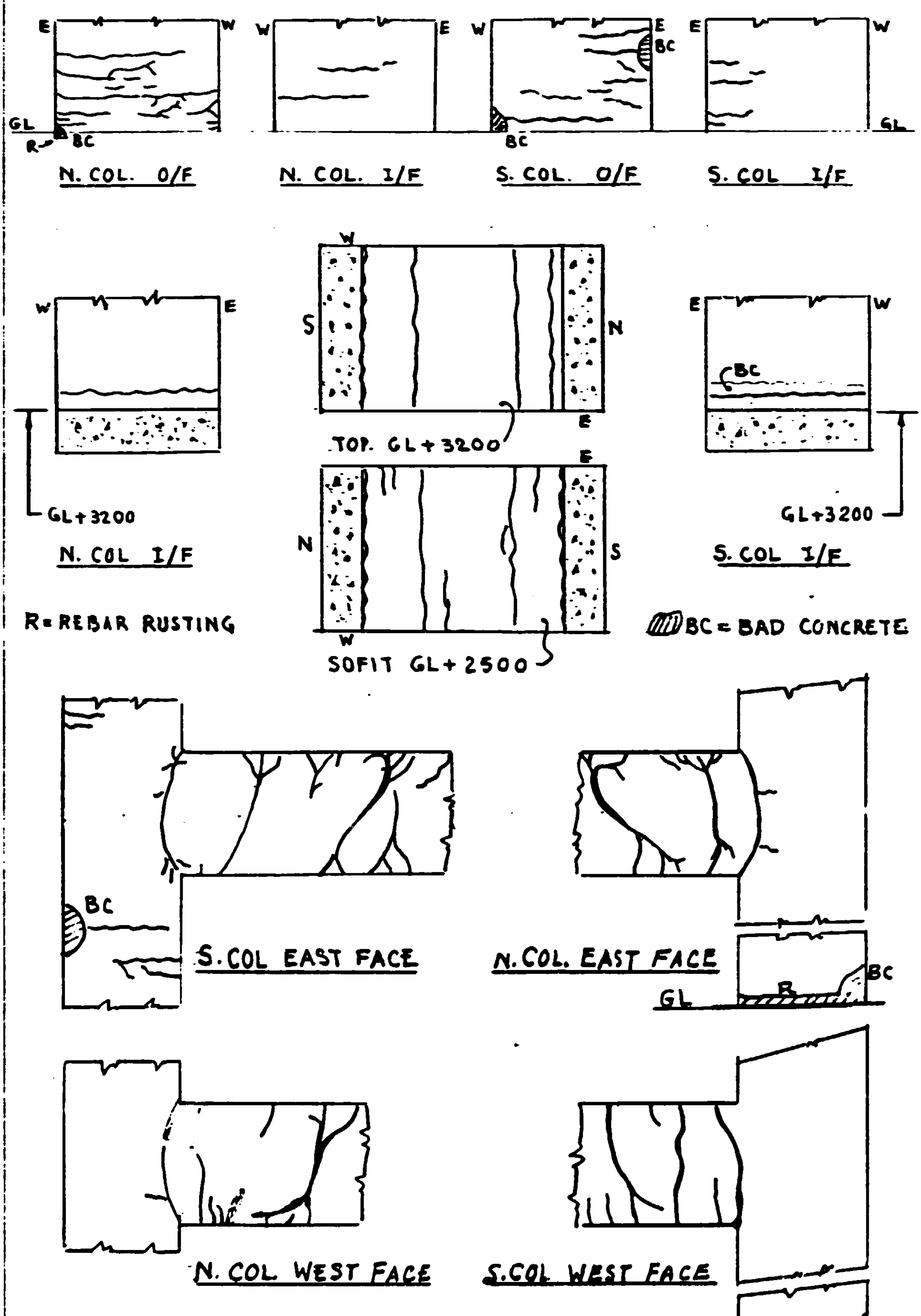

FIG. 4 CRACKS KILN SUPPORT NO.2

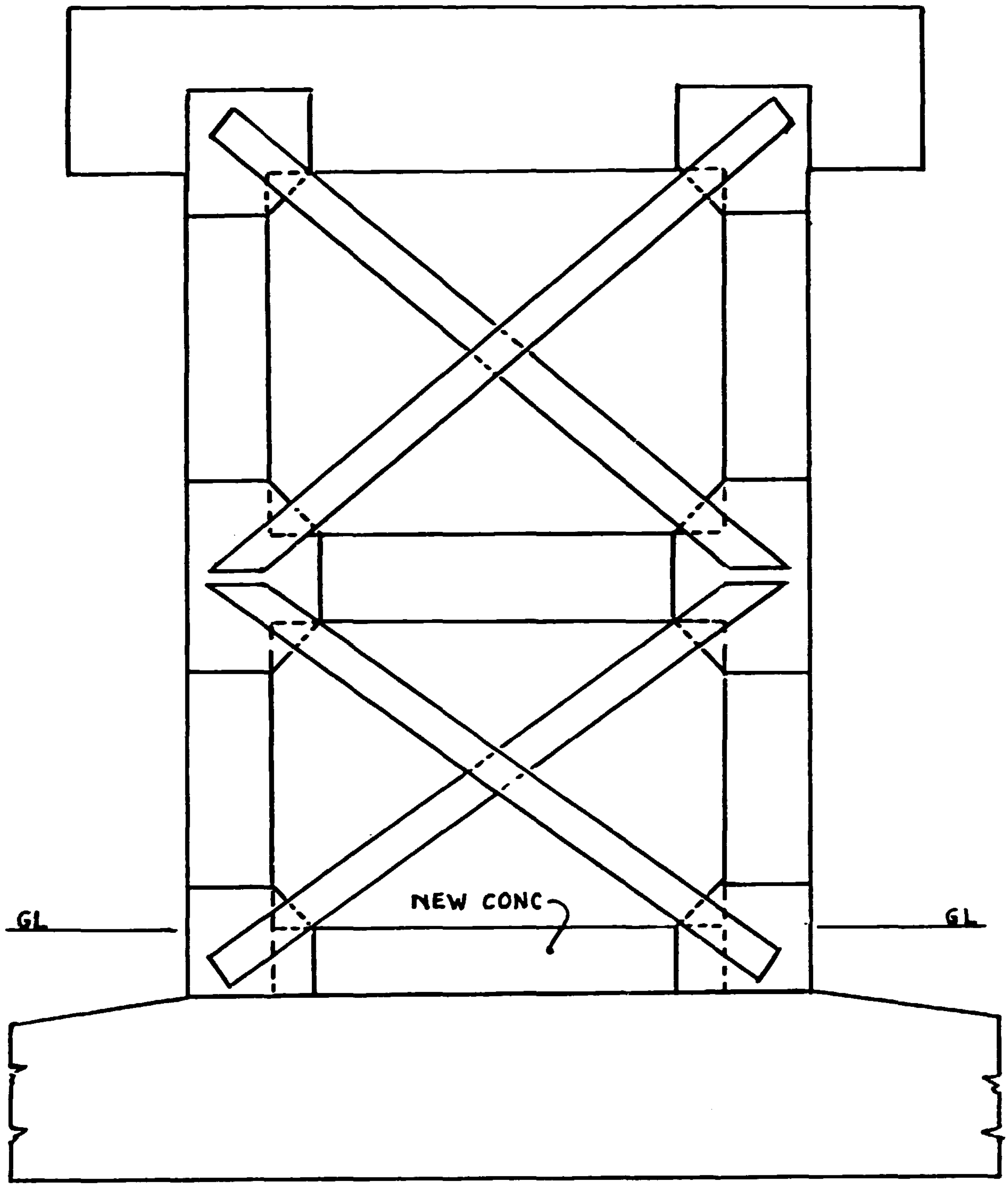

FIG. 5 RECOMMENDED MODIFICATION TO KILN SUPPORT NO. 2

Analyse the proposed braced frame, design the mild steel bracings and plate components and bolts, Fabricate the same. Unload the frame by jacking up the kiln, rectify all cracks by epoxy injection and install the bracings. For future reduction of the stresses, consider central column (not shown) if required.