13 Mar 1991, 1:30 pm - 3:30 pm

Dynamic Characteristics of Crusher Supporting Structures

P. Srinivasulu
Structural Engineering Research Centre, Madras, India

B. Sivarama Sarma
Structural Engineering Research Centre, Madras, India

N. Lakshmanan
Structural Engineering Research Centre, Madras, India

Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, 1991, St. Louis, Missouri, Paper No. 11.21

Dynamic Characteristics of Crusher Supporting Structures

P. Srinivasulu
Scientist, Structural Engineering Research Centre, Madras, India

B. Sivarama Sarma
Scientist, Structural Engineering Research Centre, Madras, India

N. Lakshmanan
Scientist, Structural Engineering Research Centre, Madras, India

SYNOPSIS

Ring granulator type crushers are installed in many coal handling plants over framed type supporting structures either in steel or reinforced concrete. The causes of excessive vibrations commonly reported from these installations are discussed. The paper describes, in particular, the nature and magnitudes of exciting forces to be considered for the safe design of supporting structures for such machinery. Two practical examples are illustrated - one involving an elevated steel structure and another a reinforced concrete framed structure, the latter supporting multiple crushers on the same floor. Pertinent conclusions are drawn for the benefit of future designers of such installations.

INTRODUCTION

The coal handling unit forms an important part in the layout of a thermal power plant complex. Its function is to receive the stock of raw coal from the mines transported over belt conveyors, segregate the same into batches of different particle sizes by means of vibratory screens and further crush the bigger sized particles with the help of crushers. With the demand for increase in generating capacities of thermal power stations, the capacities of coal handling plants have also increased of late. This has led to numerous problems of design and maintenance of machinery and their supporting structures in these plants.

Crushers used in coal mills are of different types - jaw type, cone type, hammer type, etc. Ring granulators - a recent development in hammer type coal crushers - are increasingly being installed in coal mills on account of their superior performance. They require minimum power per tonne of coal to be crushed. Some problems reported recently from such installations have caused concern to the manufacturers, operating and maintenance personnel as well as designers of supporting structures for these machinery. In some cases, misuse of operations seem to have led to excessive vibration problems in these installations, causing progressive failures of machinery components as well as parts of the supporting structure. Codal provisions for the design of supporting structures have been questioned by the engineering groups concerned for their inadequacy (Manohar and Thakkar, 1989).

This paper attempts to bring out the mechanical and structural problems involved, explain the nature of dynamic loads experienced during normal and abnormal working of these machinery and illustrate these with two case studies.

RING GRANULATORS - FUNCTIONAL DESCRIPTION

Fig.1 shows a typical cross sectional view of a ring granulator type machine in question. For the pulverising action, these machines use the method of "crushing"

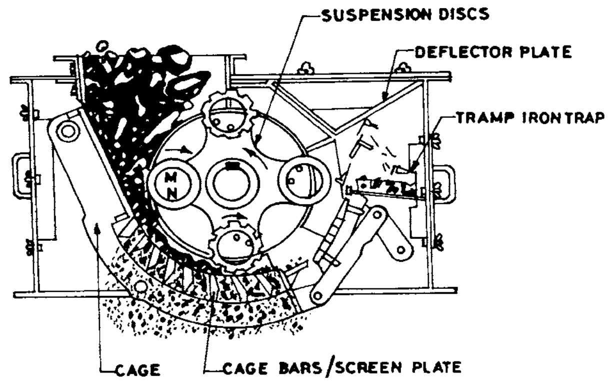

Fig. I A Typical Cross Section (Ring Granulator)

accompanied by "impact" as well as "shearing" actions. Multiple sets of crushing rings or hammers are hung from pairs of suspension shaft across the width of the rotor. The rotor is initially balanced before installation. Plain and toothed rings are placed alternately to provide the best crushing action. The layout of the rings is such that a balanced configuration results in the reactions at the bearings. The hammer rings which are generally made of cast steel, are expected to have adequate resistance to wear and tear. The tolerance in the weights of these hammers is expected to be specified by the manufacturers.

Ring granulators are driven either directly by synchronous motor having a matching speed or through a reduction gear box provided in between with necessary couplings.

The centrifugal force caused by the rotation of the shaft causes the ring hammers to strike against a plate located across the path of the falling coal which gets crushed by the pounding action of these hammers. A reduction of size from 200 mm to say 20 mm is realised by this process. Coal crushers of this type have capacities ranging from 600 to 1000 tonnes per hour. The crushed coal is finally discharged through chutes onto another conveyor belt which leads it finally to the stock yard.

DESIGN CONSIDERATIONS FOR SUPPORTING STRUCTURES

Location

Crushers are usually located at a height of say - 15 m above ground to facilitate easy feeding of coal from the overhead conveyors. The supporting structure is generally of an elevated steel or reinforced concrete framed construction. It is preferable to isolate such foundations from the main plant building. This requirement is, however, ignored in some plants leading to subsequent vibration problems.

Dynamic Loads

The dynamic loads induced by the operation of crushers are of two types:

1) Unbalanced forces caused by rotor-eccentricity and loss of hammers.

2) Shock forces induced by the impact action of the hammers.

The unbalanced forces caused the residual unbalance in the rotor are aggravated by gradual wear and tear of the hammers. Excessive wear and tear may lead to even breaking of the hammers. This causes large dynamic forces, endangering the machine and its supporting structure. There have been instances of hammers suddenly breaking when foreign bodies like boulders and showel teeth also get entry into the crusher chamber. When the hammers try to crush these hard bodies, they themselves get broken. This is obviously a result of neglect of machinery which is often reported from many plants. Efforts made to avoid such occurances by the use of magnetic separators are reported to have shown little effect. It is inevitable under these circumstances, therefore, to design crusher foundations for a certain expected number of hammers breaking from the critical locations of the suspensions.

Codal Provisions

According to the Indian Standard IS: 2974 (Part IV), the maximum dynamic force may be considered the most critical of the following three causes:

1) Maximum unbalanced force of the rotor caused by considerable wear and tear, equivalent to a net eccentricity of 1 mm.

2) Four times the balanced force stipulated by machine vendors for normal balancing.

3) Unbalanced force caused by the breakage of one hammer from the most unfavourable location.

The unbalanced force corresponding to "normal balance" condition is not usually furnished by the machine suppliers. Instead they recommend certain high values of "equivalent static forces" which are apparently related to the static weights of the machinery. Designs carried out using high values of equivalent static forces may satisfy the strength criterion, but not the dynamic criterion (eg. resonant condition). Progressive damage is inevitable in structures which are in near resonance with the operating speed of the machinery.

The International Standard ISO 1940-1973 suggests a balancing grade equal to G16 (according to their classification) with a limiting vibration velocity of 16 mm/sec for rotating machinery having low operating speeds such as crushers. The German practice is to consider one grade higher for estimating dynamic forces in foundation design - which in this case becomes G40 grade. For a 750 rpm machine, G16 grade corresponds to an eccentricity of 225 microns* while G40 refers to 550 microns.

Experience has shown that in majority of the cases, the unbalanced forces caused by the loss of hammers governs. While the loss of hammers is a usual occurance in crusher mills, loss of more than two hammers from the same suspension at the same time is rare. Unbalanced forces generated by more number of hammers breaking on opposite suspensions would only compensate each other. It is, therefore, considered a safe approach to account for "a two hammer loss" from the outer most suspension as a case of abnormal condition for which the strength criterion should be satisfied by the foundation design, while the provisions of the prevailing Indian Standard code earlier mentioned are adequate for purpose of satisfying the dynamic criteria. The dynamic criterion, according to the same code, warrants a check on the amplitude of vibration not exceeding a limit of 200 microns. This limit may be followed for foundations supporting low frequency rotating machinery, unless the manufacturers stipulate a more stringent value for special reasons. It is, however, desirable to instal in the control room an automatic tripping device for the crushers, in case a preset value of amplitude considered in design is exceeded at the bearings.

No specific mention is made in the codal provisions about the shock forces to be considered in the design of supporting structures. Fig. 2 shows a typical vibrogram

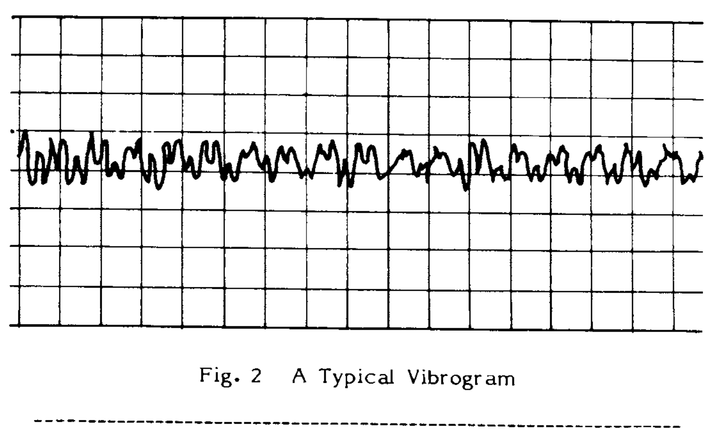

Fig. 2 A Typical Vibrogram

---

* 1 micron = 10^{-6} meters

collected from the rear bearing of a ring granulator during the process of its crushing coal. The record shows random oscillatory motion typical of a situation in which the eccentricity of a rotating shaft keeps changing. This is expected in a crusher as the centre of gravity of the coal mass changes arbitrarily within the crusher chamber. However, there is no evidence of any repeated impact or pulses seen in it.

Intermittent shock loads expected out of hammering action may, therefore, be ignored in coal mills, unless such loads are quantified by the machine manufacturers and are specially highlighted.

Use of springs and viscous dampers has been recommended for crusher installations (GERB, 1988). The dampers help in mitigating the shock influences. A well designed isolated system for the crusher assembly also results in less transmission of dynamic forces to the substructure. This application will be further illustrated in the case study example No.1 which will be explained in the next section.

Another cause for the occurance of vibrations in crusher installations is the "ceasing of crusher bearings". This occurs in a dusty environment especially when the coal is fed directly into the crusher chamber without screening the fines. When the non-drive end bearing of a crusher "ceases", the torque set up at the other end can lead to severe strain in the machine shaft resulting in high vibrations and severe damage to the machine and its supporting structure. Unless the forces resulting from such events are quantified by the mechanical engineers, the designers cannot suitably design the supporting structures to avoid damage. The case study example No.2 to be explained later, will deal with such an occurance in a running plant.

CASE STUDIES

1) A Steel Structure Supporting a Crusher

A crusher-motor assembly was erected on a reinforced concrete deck slab above a 12 m high steel framed structure (Fig. 3a). The ring granulator type crusher used in this case had been experiencing repeated breakage of hammers, the reasons attributed to it being the ingress of steel showel pieces into the crusher chamber. The steel structure experienced progressive damage leading to a near shut down stage of the entire plant. Analytical computations and also forced vibration tests carried out at site confirmed at least two resonant frequencies, both occuring below the operating frequency of 12.5 Hz (750 rpm). Dynamic computations for the two hammer breaking condition showed that the induced stresses in many members of the steel structure exceeded the yield stresses. A review of the original design calculation for the structure confirmed that no dynamic considerations were used therein. Equivalent static forces suggested by the manufacturers were only used in the design. During an investigation at site by the authors, a hammer

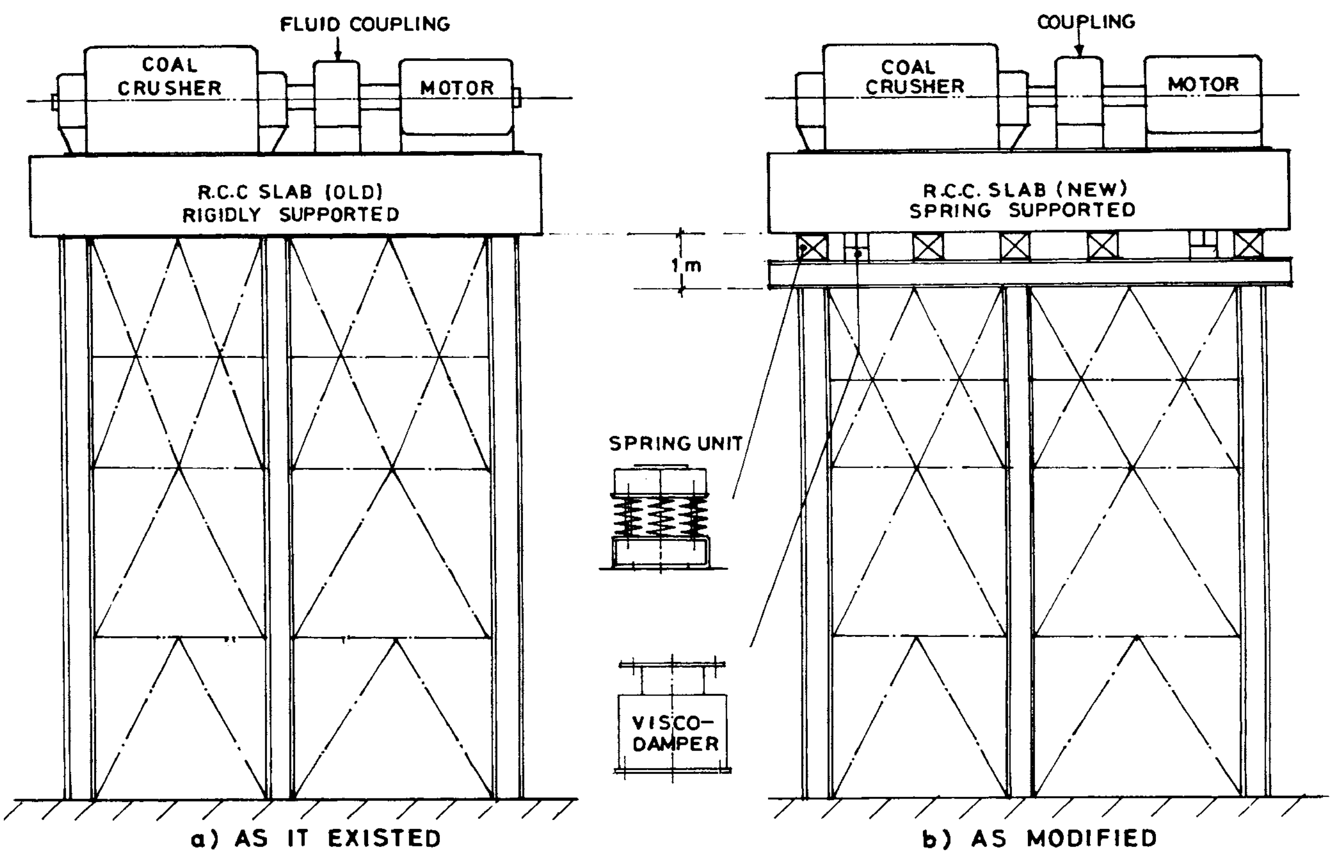

Fig. 3 Steel Structure Supporting Crusher Assembly

was purposely removed from the outer suspension, and the machine was coasted down from the operating speed. The rate of deceleration of speed during coasting down was so low (Fig. 4) that it took nearly twelve minutes for the machine to come to rest. A horizontal peak amplitude as high as 1000 microns was recorded at one of the transient resonance stages. Fig. 5 shows the variation of amplitude with frequency when the hammer was removed from the suspension. The steel structure with inherently low damping could experience "sustained resonant oscillations" during the coasting down stage. The machine in question required stoppage intermittently - depending upon the coal position - about twice or thrice a day. The progressively increasing number of cycles of large alternating stresses due to repeated resonances, had led ultimately to the failure of the structural elements.

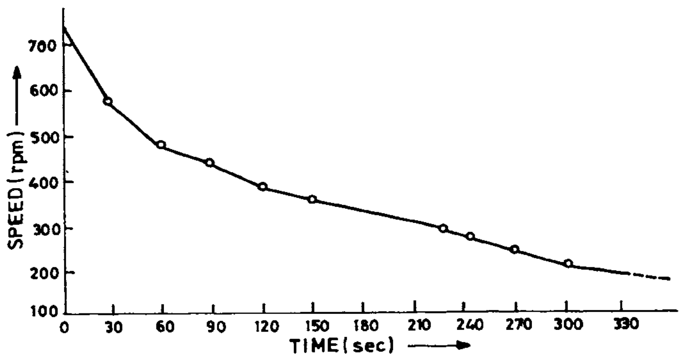

Fig. 4 Variation of Speed with Time During Coasting Down

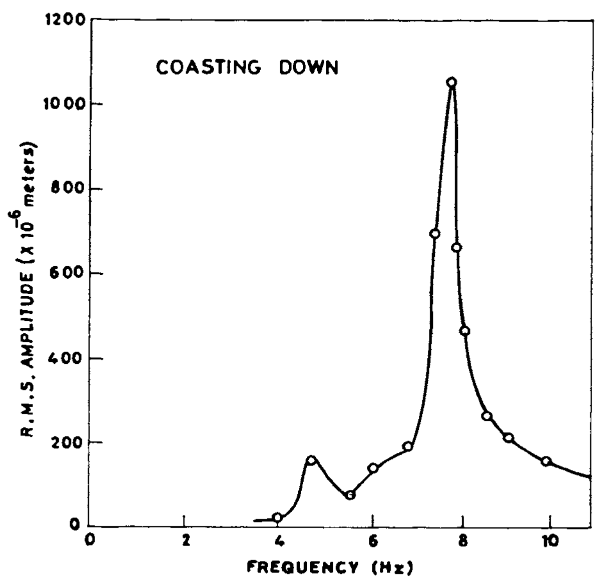

Fig. 5 Variation of Amplitude with Frequency (One Hammer removed)

A well designed vibration isolated system was incorporated as a remedy. The isolation consisted of metallic springs and visco-dampers manufactured by GERB GmbH & Co., West Germany. Fig. 3b shows the view of the installation before and after the modification. Among other things suggested were the use of mechanical brakes to speed up the rate of coasting down the speed when the machine is tripped and the use of ductile steel of such composition as to avoid frequent breaking of hammers without, however, affecting their efficiency for crushing operation.

2) A Reinforced Concrete Foundation for Multiple Crushers

Fig.6 shows the schematic 3D view of the reinforced concrete supporting structure, and Fig.7 shows the plan view of the crusher floor on which were mounted six crusher-motor assemblies. The vibrating screens were

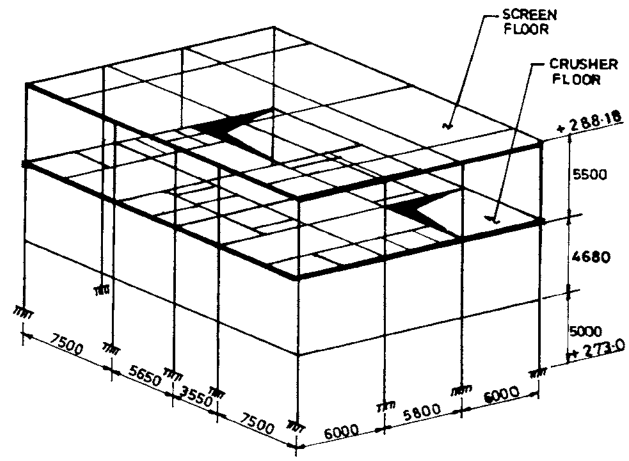

Fig. 6 Schematic 3-D View of R.C.Crusher Supporting Structure

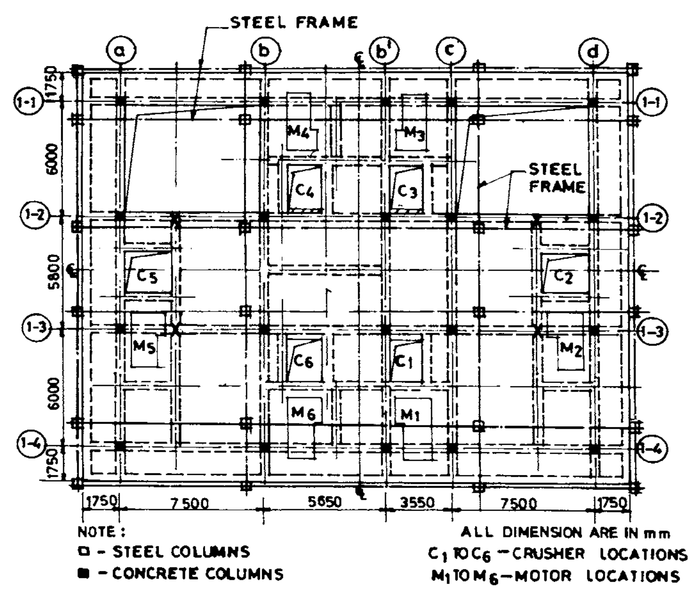

Fig. 7 Plan of Crusher Floor

placed in the next higher floor directly above each crusher unit. As seen from Fig.7, steel columns of the main plant building were seen to rise above and through the concrete floors, with the expected isolating gaps around them choked with dust and muck. After the vibrating screens were first installed and commissioned on the higher floor, it was reported that high vibrations were experienced all over the building. It was then decided to bypass the screens and feed the coal directly into the crushers. This resulted in excessive dust spreading all over the area as the operations went on. Large dumps of coal dust were seen over the floors surrounding the crushers, although arrangements were made to clear them periodically. After a few months of continuous working, the non-drive end bearing of one of the ring granulators was reported to have ceased functioning. Violent oscillations were then experienced resulting in the motor seating to get ripped open and extensive cracking of the concrete structural elements in the vicinity. The engineers of the machine suppliers maintained that the ceasing of the crusher bearing is an unlikely event to take place in a properly maintained crusher environment. They could not, however, quantify the dynamic loads expected when such a situation occurs.

Dynamic computations of the supporting structure showed that the end spans each 7.5 m long (Fig.7) were in near resonance as the mode shapes indicated. This was confirmed by the forced vibration tests subsequently conducted at site on these spans. An additional built up column was suggested at locations marked (X) in these spans (Fig.7). The members showing poor quality of concrete, as revealed from the insitu ultrasonic tests conducted at site, were grouted with a non-shrink epoxy compound.

The concrete framed structure which was originally designed for the "equivalent static forces" expected from the operation of six crushers placed on the same floor was finally found to be capable of resisting the "most adverse loading combinations" that are likely to occur when only three of the six crushers operate. The locations of these three crushers were identified as C_2, C_5, and C_6. While the fourth crusher C_4 could be retained as a standby unit, the remaining two units C_1 and C_3 along with their driving motors were suggested to be shifted to an adjacent crusher house that was being planned to meet the needs of the expansion programme. The use of vibration isolation system was not feasible in this case due to lack of required headroom and other practical problems associated with a concrete structure.

The above two case studies confirm the need for efficient planning of the layout and rational analysis for the supporting structures of the crushers. It is also recommended to introduce condition monitoring of the crusher machinery on a long term basis. This may help in improving the design criteria for future installations.

CONCLUSIONS

The mechanical and structural problems involved in ensuring vibration-free crusher installations in coal handling plants are discussed. The limitations in the codal provisions are also cited. Two case studies are illustrated to bring out the imperfections in the planning and design of supporting structures on the one hand and poor maintenance of machinery on the other. It is suggested that condition monitoring of machinery be introduced in all coal handling plants and scientific analysis of vibrograms periodically collected from the machinery bearings be carried out. This may lead to a better appreciation of the various problems involved, leading to improved criteria for the planning and design of these installations.

ACKNOWLEDGEMENT

Thanks are due to various coal handling plants and their consultants in India who had provided valuable data on the subject. The authors also wish to thank their colleagues in SERC, Madras, who had helped them in the study. This paper is published with the permission of Director, SERC, Madras, India.

REFERENCES

GERB: Vibration Isolated System for Crusher Foundations - Catalogues, 1988.

Indian Standard Code of Practice for Design and Construction of Machine Foundations, IS:2974 (Part IV) - Foundations for Rotary Type Machines of Low Frequency (First Revision - July 1980).

International Standard ISO 1940 - 1973, "Balance Quality of Rotating Rigid Bodies," ISO Standards Handbook 4, 2nd Edition, 1985.

Manohar, S.N., "Design Criteria for Crusher Foundations for Power Plant Machinery", paper presented at the workshop organised by National Thermal Power Corporation at New Delhi during 9-10 November 1989

Ring Granulators - Manufacturer's Catalogues & private collections.

Srinivasulu, P., Lakshmanan, N., Muthumani, K., and Sivarama Sarma, B., "Excessive Vibrations in the Supporting Steel Structure for an Elevated Crusher - A Case Study", Proc. of VIII Symposium on Earthquake Engineering, Roorkee, India, Vol.I, pp 363-369, Dec.1986.

Srinivasulu, P., and Lakshmanan, N., "Vibration Problems in Ore and Coal Handling Plants", Notes on lectures delivered at SERC Course, 1990.

Thakkar, M.C., "Coal Crusher Foundations - Designers' Dilemma" - paper presented at the Workshop on Foundations for Power Plant Machinery organised by NTPC, New Delhi, 9-10 November 1989.