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Seismic qualification of diesel engine. An analytical approach

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ABSTRACT

The diesel engine is an important equipment from the standpoint and thereby it is required that the engine should be able to perform its functions in the event of a seismic hazard. Hence it is necessary to carry out the seismic qualification test of the engine before its installation. In the paper a case study of the seismic qualification of the diesel engine by analysis has been presented. The diesel engine is a very complex equipment and it is an impossibility that all the components can be included in the modelling. In the study a systematic and rational basis for the modelling of the engine components and the auxiliaries has been given with sufficient details alongwith the results of the analysis. Finally some conclusions are drawn which may serve as useful guidelines for the seismic qualifications of other engines.

1.0 INTRODUCTION

An emergency diesel engine is required to maintain its functionality in the event of any hazard especially during a large scale earthquake. The diesel engine in consideration are one of those of the Fire Water (F.W.) units in one of the Nuclear Power Plants of India. The engine is used to drive the submerged vertical F.W. pumps through a gear-box. The engine is a six cylinder two stroke diesel engine with continuous power rating of 115 kW [vide Table-1 for basic engine data].

The original design for the engine for the normal operating conditions was carried out by the manufacturer. For its application in the nuclear power plant, it is necessary to ascertain its operability under seismic conditions. The objective of the seismic qualification process is to demonstrate the structural integrity of the system under the conditions of a postulated design basis earthquake. In this paper, we have given a brief description of the seismic qualification of the engine through an analytical approach. The matter presented here is based on the report [1] submitted to Nuclear Power Corporation of India for one of the power projects.

2.0 MODELLING & ANALYSIS

The major constituents of the diesel engine are the crank-case, the cylinder block, crank-shaft, cam-shaft, the connecting rod, gudgeon pin, the bearings and the connecting bolts. The auxiliaries include the cooling water system, oil pump and exhaust piping The auxiliaries can be decoupled from the major system due to their small mass ratios.

The FEM discretization of the engine is shown thru' Figs. 1-7. Table-2 gives the element type and the number of elements for the different components. The journal bearings for the crank and cam shafts have been modelled using high stiffness spring elements. The sliding behaviour of the piston has been simulated with the help of high stiffness spring elements normal to the surface of contact of the piston with the cylinder.

The mass lumping for the crank case and the cylinder block is done automatically. For the rotating parts consisting of the piston, connecting assembly and masses are lumped so as to form an equivalent dynamical system [2,3]. The axial rotation of the non-driving end of the crank-shaft has been locked to remove the rigid body mode of rotation.

The fundamental frequency of the engine [Table-3] is 39 Hz. which shows that the system can be treated as a rigid block. Thus, an equivalent static analysis can be performed with the ZPA instead of a dynamic analysis. The ZPA used is 0.31g which is at the floor level of the Fire-Water Pump House. The analysis is performed for several cylinder positions and the results of the most severe condition is reported.

3.0 RESULTS AND DISCUSSIONS

The frequencies were determined considering the engine footings to be rigidly connected to the foundation. But actually the foundation bolts have certain flexibility and the fundamental frequency of the system will be considerably lower. In order to maintain the condition of a rigid support we have increased the frictional forces on the engine footings by suitably pretensioning the connection bolts. The pretensioning force can be determined as follows

$$F_T = F_{sh}/\mu + F_{sv} - W \qquad \text{.......(1)}$$

[where, F_{sh} (F_{sv}) is the seismic force on the engine in the horizontal (vertical) direction, W the weight of the engine and μ the coefficient of friction]

Assuming a value of 0.3 for μ [for sliding between steel and concrete surfaces] a pretensioning force of 400kg has been found.

The factor of safety (F.S.) of different components of the engine is shown in Table - 4. It is seen that the F.S. for the deflection of the gudgeon pin is quite low. We shall now determine limiting range of values for factors for seismic accelerations in horizontal and vertical directions. This may be obtained by solving the following optimization problem.

$$\text{Min.} \{ [\phi(\alpha_h,\alpha_v) = d_a - d_{op} - \sqrt{((\alpha_h d_h)^2+(\alpha_v d_v)^2)}] \geq 0 \} \qquad \text{.......(2)}$$
$$\alpha_h \geq 0;\ \alpha_v \geq 0$$

where, d_a = Allowable deflection of the gudgeon pin
d_{op} = Deflection under operating conditions
d_h, d_v = Deflections in horizontal (resp. vertical) directions under vertical loadings
α_h, α_v = Factors for seismic accelerations in horizontal (resp. vertical) directions over the base value of 0.31g

The maximum coefficient for pure horizontal excitation is 2 and for pure vertical excitation is 6.

4.0 CONCLUSIONS

An analytical model has been developed for the diesel engine. The analysis demonstrated the structural integrity of the component members. The magnitude of the pretensioning force on the bolts on the footings has been determined so as to prevent any sliding during the seismic event. Some members have a relatively low safety margin and the range of values for the ZPA have been found for the limiting capacity of the weakest member. The information obtained from the analysis may be appended in the database and may prove to be useful in the qualification of similar engines.

5.0 REFERENCES

1. Seismic Qualification of Vertical Fire-Water Pumps; Report No. M&P/91R01/01/SR-Vol. II
2. Maleev, V.L.; Internal Combustion Engines; McGraw-Hill Kogakusha, Tokyo, 1945.
3. Kovakh, M.; Motor Vehichle Engines, Mir Publishers, Moscow, 1979.

Table 1 : Engine Data

1.	No. of Cylinders	6
2.	Bore (mm)	111
3.	Stroke (mm)	127
4.	Piston Speed (m/sec.)	8.47 at 2000 rpm.
5.	Compression Ratio	15:1
6.	Firing Pressure (kg/sq.cm.)	110
7.	Injection Pressure (kg/sq.cm.)	217
8.	BMEP (kg/sq.cm.)	8.96 at 2000 rpm.
9.	Continuous Power Rating	115 kW at 2000 rpm.

Table 2 : Modelling Description of Components

Serial No.	Item Description	Element Type	No. of Elements
1	Bottom Sump	Plate	46
2	Crank Case	Plate	100
3	Cylinder Block Case	Plate	358
4	Cylinder & Piston	Plate	288
5	Support Footings	Plate	64
6	Partition Beams	Beam	5
7	Crank Shaft & Connecting Rod	Beam	50
8	Cam Shaft	Beam	12
9	Piston Pin	Beam	12
10	Foundation Bolts	Beam	4
11	Cylinder Liner	G-STIFF	144
12	Crank & Cam Shaft Brg.	G-STIFF	32

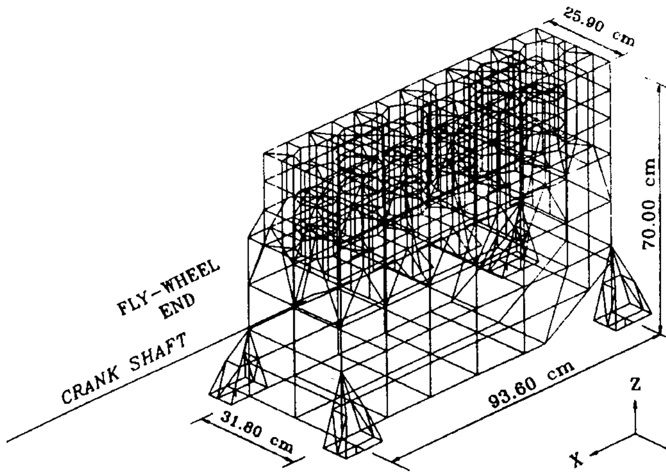
Table 3 : Frequencies of the Engine

Mode No.	Frequency (Hz.)
1	39.7
2	41.1
3	93.3
4	97.0
5	136.5

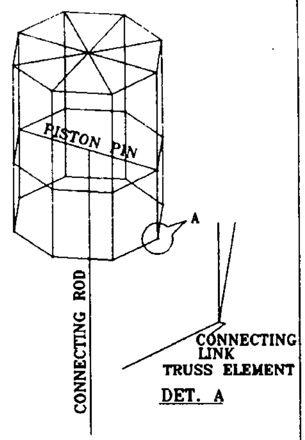
Table 4 : Factors of Safety (F.S.) of Critical Components

Components	Item Checked	Magnitude[1]	F.S.
Connecting Rod	Whipping Stress	376	18
	Compressive Stress	1697	4
	Buckling Load	9263	2.6
Crank Shaft	Normal Stress	9844	39
Journal Bearing	Bearing Stress	3	80
Cylinder Liner	Tangential Stress	1046	2.4
Gudgeon Pin	Bearing Pressure on Piston Boss	431	16
	Bearing Pressure in Connecting Rod Small End Bush	465	15
	Bending Stress	1102	6.4
	Tangential Shear Stress	775	4.6
	Maximum Deflection	2.19E-03	1.2

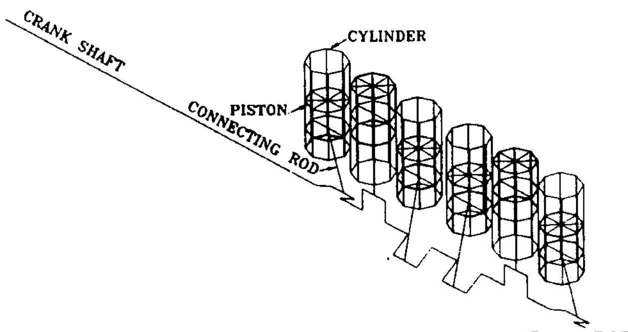
[1]Note : Stresses are in kg/sq.cm., Forces in kg, Deflection in cm.



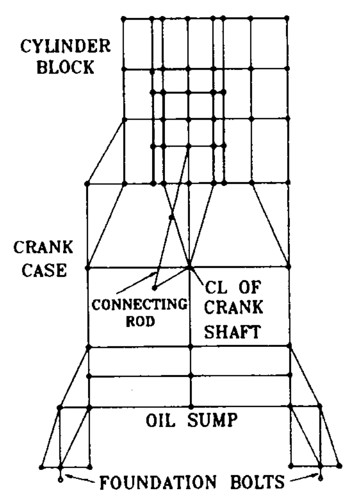
3D FINITE ELEMENT MODEL OF THE DIESEL ENGINE
FIG. 1



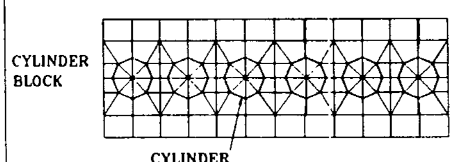
MODEL OF PISTON WITH CONNECTING ROD
FIG. 3



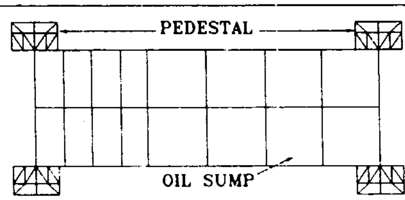
MODEL OF CYLINDER WITH PISTON, CONNECTING ROD & CRANK SHAFT ARRANGEMENT
FIG. 2



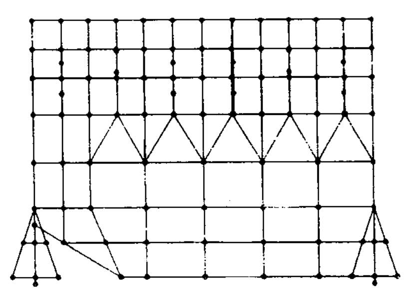
END VIEW
FIG. 4



TOP VIEW (PLAN)
FIG. 5



BOTTOM VIEW (PLAN)
FIG. 6



FRONT VIEW (ELEVATION)
FIG. 7