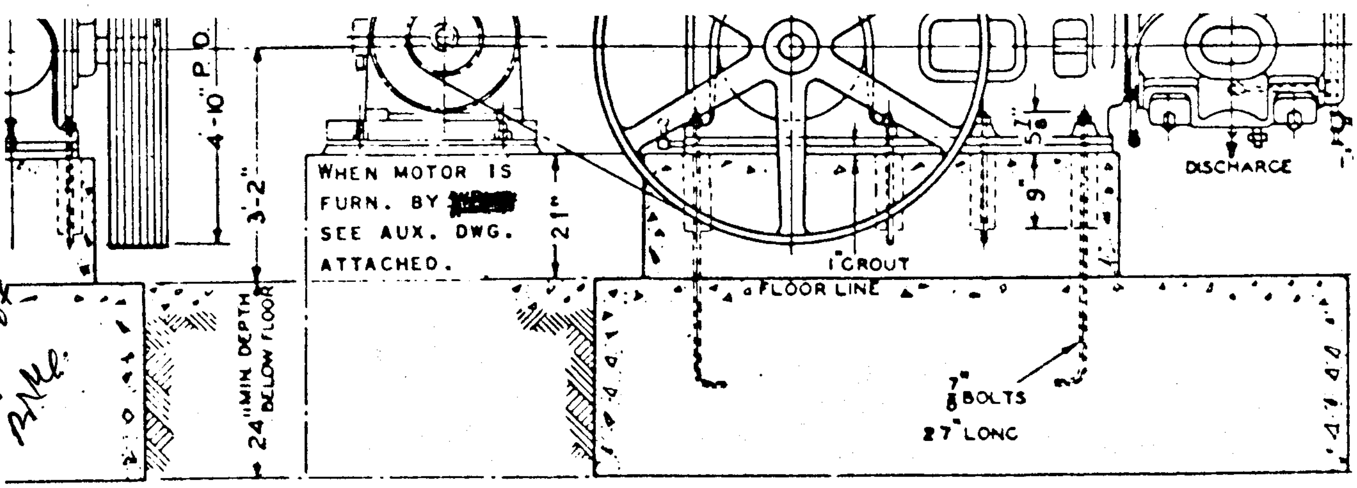

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6-22-73 Jack – might be of interest. [initials]

Don't Gamble On Machinery Foundations

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DON'T ALWAYS RELY on vendor's drawing to give you a foundation that holds vibration to within acceptable limits. Modify his instructions to suit your particular application.

Installation of compressors, vacuum pumps, engines and other machines that offer the potential for heavy vibration must have a firm foundation. Vibration not only causes personal discomfort when it's adjacent to working areas or offices, but can also result in failure of switches, gages, controls and cause cracks in flooring and walls.

All too often the vendor supplies you with only a small foundation drawing (Fig. 1), which often proves inadequate. Vendors, traditionally, will not take responsibility for your foundation because you build it.

So when trouble occurs, you ask "how did it happen, we followed the drawings to the letter?" Actually you didn't.

It's important to note that all vendor's drawings are based on "good, dry, firm soil conditions" at the site. Generally, this information will be found in a small note in fine print, or appear in separate instructions. Others will add a note giving the horizontal unbalanced forces and couples of the machine.

In too many cases this information is regarded as "not pertinent," even if in your case the excavation for the foundation shows moist sand and clay at the support level. It's important to observe site conditions and take the necessary steps to ensure a tailored-to-task foundation.

Make Important Soil Tests

Regardless of the size of the reciprocating machine you are going to install, have a soil exploration test made to a depth of at least 8 to 10 feet (for up to 200 horsepower units). Testing laboratories will then determine the soil bearing pressure ability (they will measure two or three points to be certain) of the strata at foundation support level. This gives you the "allowable" static soil loading in pounds per square inch.

You can determine the "allowable dynamic soil load" by dividing the static load by 4. As a preliminary check, add weight of the machine and foundation block and divide by the dynamic soil load to determine the required area in square feet for the bottom surface of the block. If this area is greater than the area shown in the vendor's drawing, then a mat will have to be added to support the block and to distribute the mass over the larger area. A piling plus mat extension may be called for if the soil tests show a water table above the support level.

But how do you crank in the unbalanced forces and arrive at a solution? What vibration limits are allowable, and how can these be determined?

Basically, a vibration limit of .005 inch is considered a suitable design. This is measured at the centerline of the machine. If the unit is a horizontal compressor, measure it at cylinder head center.

The importance of soil base tests are quickly recognized when you consider that the vendor's drawing is predicated on dry, firm soil of between 1500- to 2000- lbs./sq. ft. safe dynamic load. Table 1 gives you the average (tested) values of various soils.

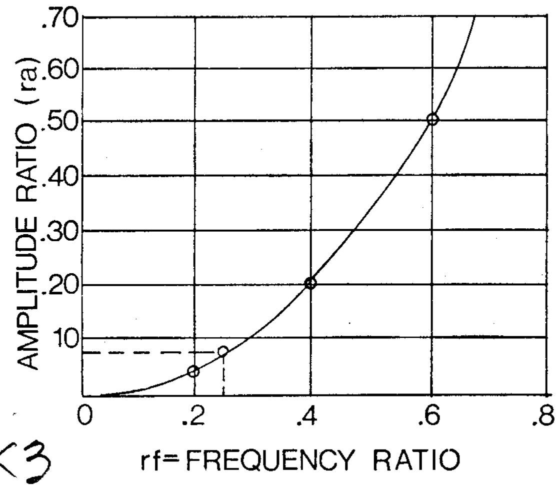
22000#/150 = 146.8 CF, 146.8/33 = 4.45' deep

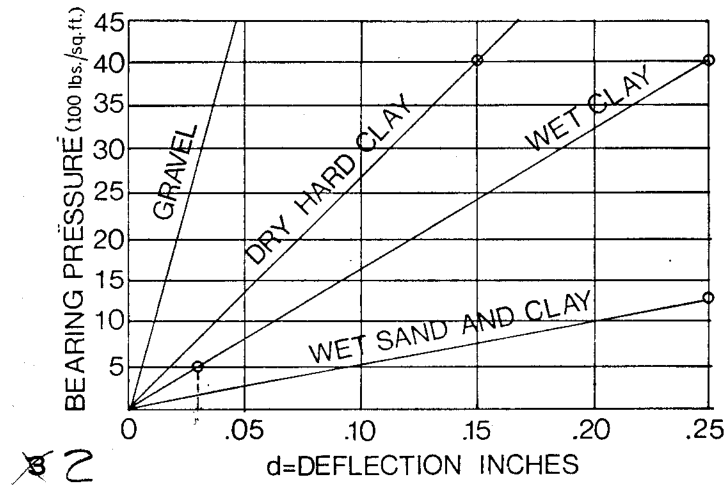
Allowable Vibration And Unbalanced Forces

In this example, assume a small 12x13-inch motor driven horizontal compressor weighs 10,000 pounds. The vendor's drawing shows a block (11x3x33 sq. ft.) which weighs 22,000 pounds (use 150 pounds per cubic foot for reinforced concrete). This gives us a total weight of 32,000 pounds. ?

The dynamic load required (32,000 ÷ 33) is 970 lbs./ sq. ft. This is equivalent to 3880 lbs. sq. ft. (970 ×4) required static load. As you can see from Table 1, dry, coarse sand or gravel is needed for support.

In our case we found soft clay at the 3 foot depth support level. It has an allowable dynamic loading of 500 lbs./sq. ft.





Our solution is to put a mat (14x6 feet) under the block which will add 1½ feet around the block. By making the mat 9 inches deep, we add 9500 pounds to the foundation and come up with a new total of 41,500 pounds. The new dynamic pressure becomes 495 lbs./sq. ft., which is acceptable for the soil in question.

Since all soil is elastic, the disturbing forces can be related to the ratio of soil frequency (f_s) and unbalanced force frequency (f). Natural frequency of the soil is determined by the equation $f_s = \sqrt{35400/d}$, where d is the soil deflection under applied load (Fig. 2). This relation is termed frequency ratio (f/f_s).

Figure 3 shows how the frequency ratio is related to the amplitude ratio. This is the same as the calculated free amplitude of movement (a_f) divided into the expected amplitude (a).

A foundation tends to rock about a point at the bottom surface. You can calculate this movement with the equation $A = (91)(F)(D)/I(\text{rpm})^2$, where:

F = unbalanced horizontal force in pounds.
D = distance in feet from the bottom support level to the center of machine.
I = moment of inertia of the block plus mat and machine in lbs./ft.³.
rpm = rotative speed of compressor in revolutions per minute.

Then the expected amplitude becomes $a = (A)(D)(12)(r_a)$.

Now back to the problem. The vendor's drawing shows a block 11 feet long by 4.4 feet high. Using Figure 2, the solid natural frequency corresponding to 495 lbs./sq. ft. is .03, which gives us ($\sqrt{35400/.03}$) 1095 cycles per minute. Compressor speed is 300 rpm, therefore frequency ratio becomes 300/1095 or .272.

Amplitude ratio on the vertical scale in Figure 3 is .07. Our vendor's print showed an unbalanced force (F) of 4000 pounds horizontal. Distance (D) from bottom of mat to machine centerline is 6 feet. Then, disturbing torque is FD, or 24,000 lb./ft.

Check the total amount of inertia of the block for each section by using the equation $I = (l^2 + h^2 + 12c^2)/386$, where:

W = weight of section.
l = length.
h = height.
c = distance from bottom support level to center of gravity of the section.

Inertia for the block is (22000(121+19+104)/386) 14,000 lb./ft.³.

Inertia for the mat is 9500(195+.5+1.7)/386 or 4900 lb./ft.³.

Compressor is $MD^2/32.2$ or (10,000)(36)/32.2 or 11,200 lb./ft.³

Total moment of inertia becomes 30,100 lb./ft.³.

Then determine the angular displacement (A) of the entire foundation and the machine from the previous equation: (91)(4000)(6)/(30,100)(300)(300) = .00081 radians. Calculate free amplitude: $a_f = (A)(D)(12)$, or (.00081)(6)(12) = .058.

Expected amplitude equals free amplitude multiplied by amplitude ratio, or $a = (a_f)(r_a)$ or (.058)(.07) which gives you the result of .0045 inches. This is the actual movement to be anticipated at the centerline of the machine (based on our example of a horizontal compressor).

These calculations show us that we have obtained a design that is within the allowable .005 inch movement, prescribed minimum.

Usually, damping from the surrounding soil will reduce this some 20 to 30%, or about .0034 inch.

If the compressor has other unbalanced secondary force, or couples, these must be added to your calculations, and the proper modification made — if necessary. The secondary effect will add about an eighth or a quarter to the calculated movement. ●

Table 1: Soil Static/Dynamic Load Values

Type Of Soil	Safe Static Load (lbs./sq. ft.)	Safe Dynamic Load (lbs./sq. ft.)
Rock	8000	2000
Dry Gravel	4000	1000
Dry, Coarse Sand	4000	1000
Dry, Fine Sand	3000	750
Firm Clay	2500	625
Soft Clay	2000	500
Wet Clay	1000	250
Wet Sand & Clay	1500	375
Alluvial Soil	1000	250