Set guidelines for engine foundations

Before you install a foundation for new engine-driven equipment or consider modifying an existing block for a new machine, review these practical suggestions based on current field experience

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Although much general data on foundation design has appeared in the literature, information on engine foundations has been limited. Few papers have addressed this complex area of engineering. We will look at the general types of mountings for engines and driven machinery, the normal configurations, and the technical details needed for consideration for a satisfactory installation.

The basic theoretical concept of an elastic system undergoing cyclic load disturbance gives a rational approach to adequate foundation design for reciprocating engines and compressors, of course. Soil-frequency investigations and resonance studies of field installations have filled a gap in technical knowledge, and permit designing for relatively adverse conditions. Because a correctly designed foundation should reduce transmission of vibration from unbalanced forces or couples in the machine itself, the foundation mass and its distribution will be determined from inertia calculations and soil-frequency data.

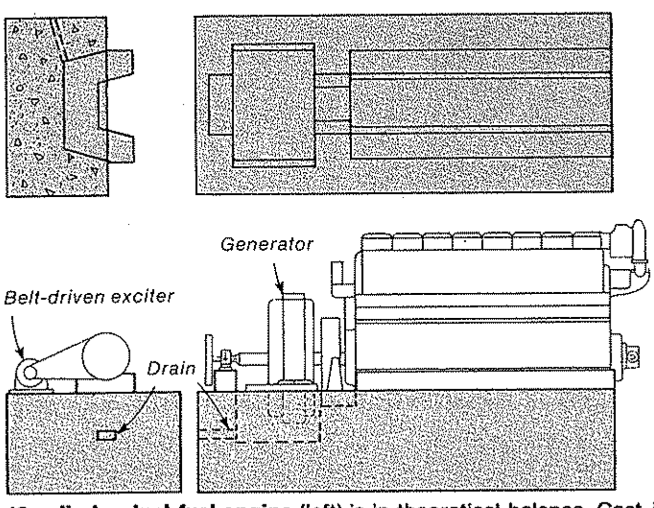
Nature of the soil, its physical properties, density, moisture content, cohesion characteristics, and the ground-water level all influence the basic design. Either compaction or piling becomes mandatory to avoid settlement. Foundation distortion under adverse temperature conditions has been recognized as more critical now, because horsepower output per unit of contact area between engine and substructure has increased.

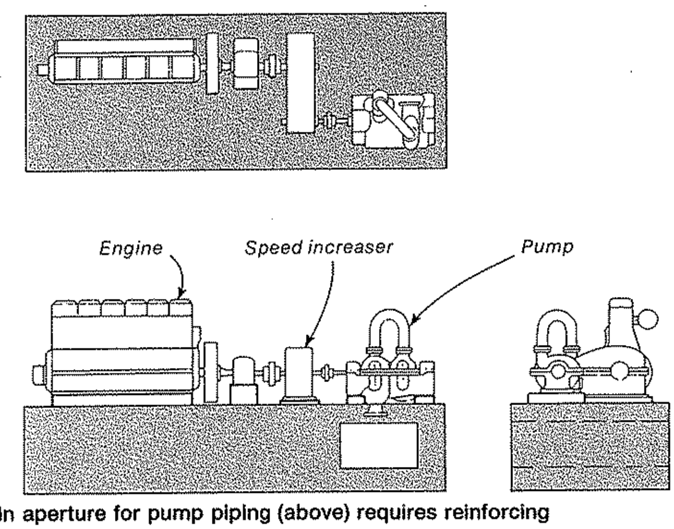
The function of the foundation is to maintain the engine at its correct initial elevation and to keep the rotating shafting in permanent alignment. Therefore, contributory causes of any deviation deserve close attention. Before we look at details of engine foundation work, let's review the principal features of typical engine-drive configurations and foundation-block shapes.

Typical configurations

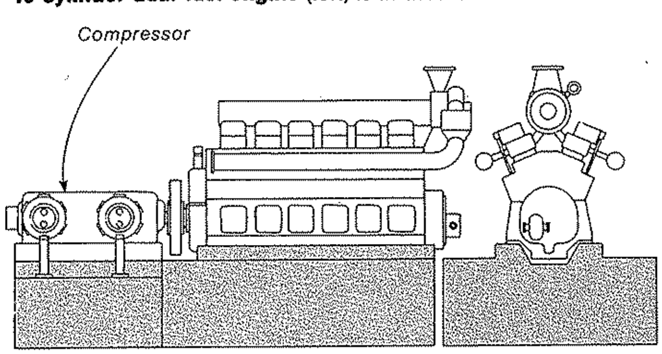
Directly below at left is a V-type engine driving a generator. The exciter is belt-driven. Although the resultant external disturbance in horizontal, vertical, and tilting directions is theoretically zero, an unbalance of 1% of the inertia of one cylinder should be provided for.

With good soil, foundation width is not less than the distance from crankshaft center to foundation bottom. For stability here, the center of gravity of the

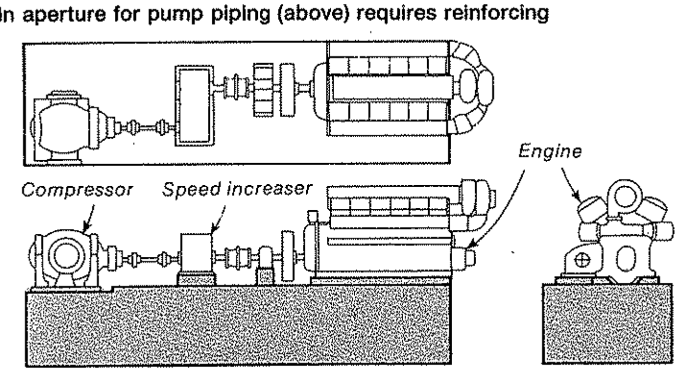




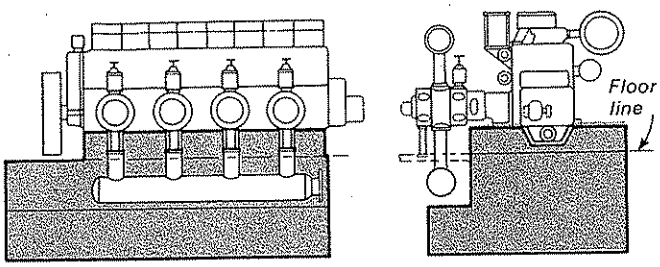
16-cylinder dual-fuel engine (left) is in theoretical balance. Cast-in aperture for pump piping (above) requires reinforcing



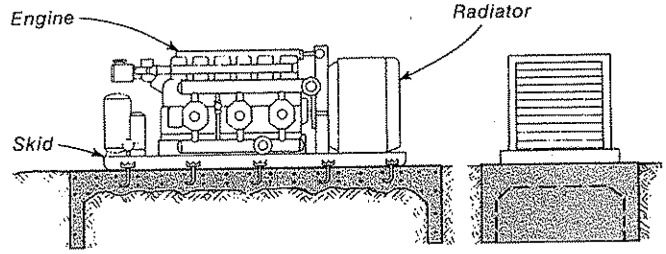
Horizontal pipeline compressor, balanced and opposed, serves as shafting support, eliminating outside bearing and mount



For centrifugal process compressor, outboard bearing supports flywheel. Drive is by quill shaft, flexible coupling



Angle compressor engine foundation can be set on reinforced mat that serves to support other units in the installation



Angle compressor skidded with auxiliary equipment rests on shallow slab, which has deep sidewalls enclosing soil mass

combined equipment and foundation must be below the foundation top. Base elevation is selected to allow operators to adjust such equipment as injection pumps, gas-metering valves, and governor control. Platforms or ladders may be needed if the base elevation is high.

Generator pits should conform with clearances prescribed by the manufacturer. The pit depth otherwise should be not less than 60% of the stator outside diameter, measured from the shaft centerline. Pits require suitable drains. Openings for conduits must be adequate for generator leads and other wiring.

Outboard bearings generally have baseplates and shims for shaft alignment. Insulation of generator and outboard-bearing bolts prevents bearing deterioration from stray currents.

A centrifugal-pump drive through a speed increaser, with flexible couplings on the low- and high-speed shafts, is shown in the upper right figure on the preceding page. Pump and gearset may be on a common welded subbase, or each may be on an individual pedestal. An outboard bearing supports the flywheel of the 6-cylinder engine and permits adjustment for crankshaft alignment.

Selection of coupling types depends on the torsional-vibration characteristics of the drive system. The structure for foundations for this equipment is usually of the high-pedestal type.

Compressor drives may be for either reciprocating or centrifugal machines, as shown at bottom of the preceding page. For the 3200-hp balanced and opposed machine, both compressor and engine are rigidly flanged together, with the flywheel sandwiched between.

A multistage centrifugal compressor requires a speed-increasing gearset (lower right, preceding page). Hydraulic couplings also have been installed, to reduce and isolate harmful torsional vibration resonance in the operating range of these 514-rpm engines.

High residual imbalance

Angle engine-compressor units, supplying much of the need in pipeline and gas-gathering service, are prone to residual imbalance and couples of both primary and secondary modes. These cause forced vibrations of engine and block, with serious amplitudes under certain soil conditions. Careful evaluation of the engine is necessary for counterweighting the crankshaft and sequencing the firing of engine cylinders if disturbance is to be minimum.

The foundation designer must know these unbalanced forces so he can determine mass and its distribution, in the form of mat extensions or piling, say, and reduce the effect of the unbalanced forces on the structure. In these machines, compressor reciprocating forces may be balanced by additional weights on crossheads, by selection of piston material, and by disposition of compressor cranks.

The angle engine-compressor at the upper left has a two-cycle gas engine with horizontal compression cylinders. The reinforced mat under machines such as this increases the natural frequency of the foundation design.

Where soils are moist and noncohesive, a bathtub design is preferred, placed on piling. Walls and mat are cast as an integral unit. If portability is a prime consideration, the angle compressor may be completely assembled on a structural framework, with its heat exchangers and controls. In the figure at the upper right, short foundation bolts attach the skid to the foundation slab. The engine is grouted to the skid for alignment purposes, and the skid is grouted to the slab at final setting.

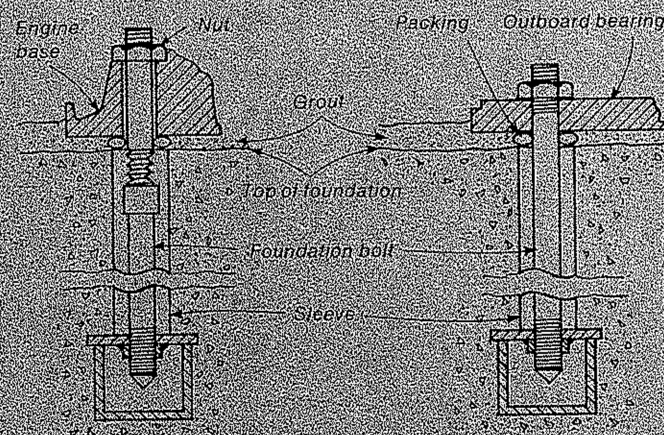
Minimum vibration transmission may be needed where personal comfort is important. Power plants adjacent to dwellings, and individual generating units for office buildings, are examples. Such installations are flexibly mounted, on springs or other suspension means. A reinforced block may be cast around a fabricated steel chassis, with the unit and block on projecting H-beams that ride over spring-type isolators. A foundation block on solid ground supports the isolators. The lower left figure on the next page illustrates this.

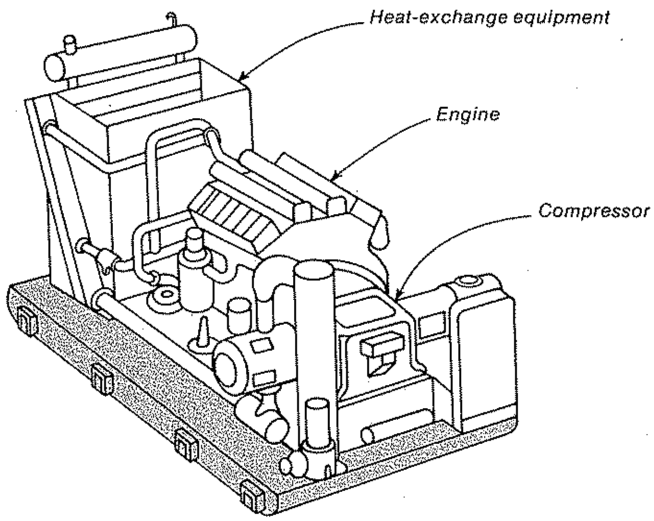
Where adverse soil conditions prevail

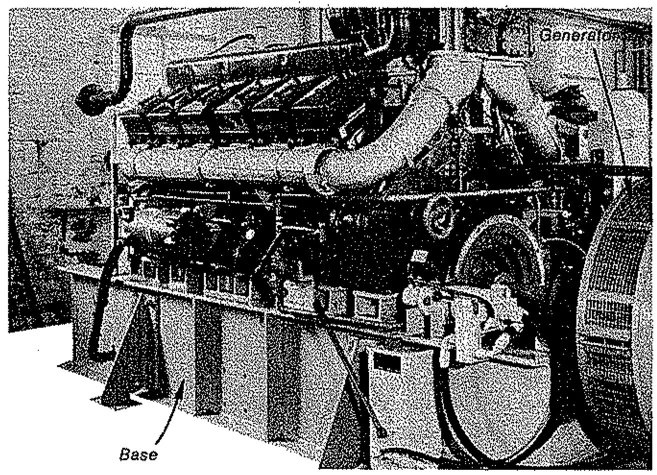
Choose engine foundation-bolt type and material carefully

Foundation bolts can be a source of difficulty because of breakage and misalignment. Bolts must be strong enough to hold the engine to the foundation block, and their design and installation must avoid any excessive stress concentration from bending or eccentric loading. Two types of bolts are installed—removable and rigid. The former (at right) is two-piece, for places where machine clearances will not let a long one-piece bolt be withdrawn. A rigid bottom section is firm in the foundation block, and a short upper bolt screws into a threaded coupling welded to the lower section. The one-piece design is at far right.

Recommended bolt material is hot-rolled ASTM A107, with tensile strength of 60,000 lb/in.^{2} and elongation of 25%. Normal practice is to suspend the bolt from the template with a sleeve providing about 1 in. clearance around the bolt. A box built under the bottom plate will give clearance for adjustment of bolt height and will prevent concrete from locking the threads.







Steel assists concrete. A fabricated steel skid (left) supports assembly with its high-speed gas engine driving through a flexible coupling. Differential expansion between compressor frame and engine base makes careful alignment a must. Deep steel base (above) is an alternative to deep generator pit

which would eventually result in settlement, foundations must go through the soft strata to solid soil, rock, or refusal. Steel, concrete, or timber piles are driven. Piling that can penetrate to stiffer soils is preferred to friction piling. Certain soils that are impervious to soil-solidifying chemical treatment may warrant consideration of friction piling where strata depths exceed 150 ft.

Point-bearing piles tend to increase the stiffness and raise the natural frequency of foundation resonance. Batter piles give lateral stability. Where batter piles go in, the fill must be placed carefully. In soft clay soils, such piles may be displaced enough to cause settlement of the block. Batter piles are usually omitted on sites with soft soil or where heavy fill is needed.

In preparing the foundation, proper bracing is necessary. The excavation bottom should be 6 in. below the foundation bottom, and hand-cut to finish so as not to exceed a tolerance of ⅛ in. in 10 ft from the lines shown on the plans. A bed of well-graded sand should bring the level up to that of the concrete. The sand should be compacted to give the right bearing capacity and density. Place underdrains as required by the plans. Forms can be wood or metal, built and braced to give a true finished base.

Block needs reinforcing

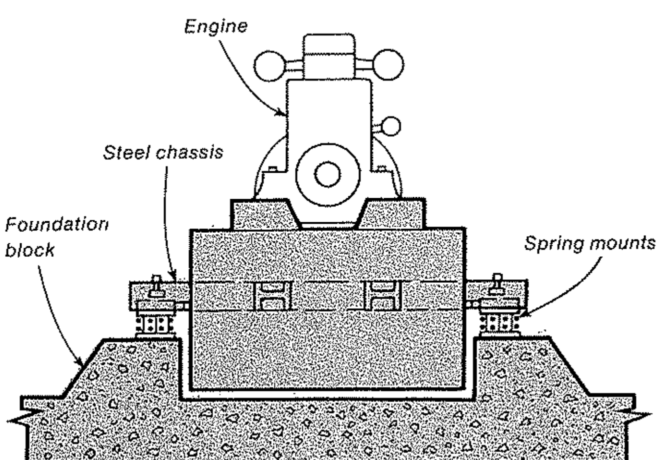
Various methods serve for reinforcement of the concrete block. The choice depends on soil condition, stability of the retaining wall, and type of engine mounting. Rebars like those in the figure at the lower right extend vertically and horizontally, at spacings depending on size and surface location.

Crossbars in the horizontal plane can be covered by bars in the vertical plane, with 3 in. cover from the vertical bars' outside diameter to the outer surface. In the foundation horizontal plane at bottom, longitudinal bars are under crosswise bars, with 3 in. cover over the outside diameter of the longitudinal bar. Top-surface cover can be 1 in. above the outside diameter of crosswise bent bars.

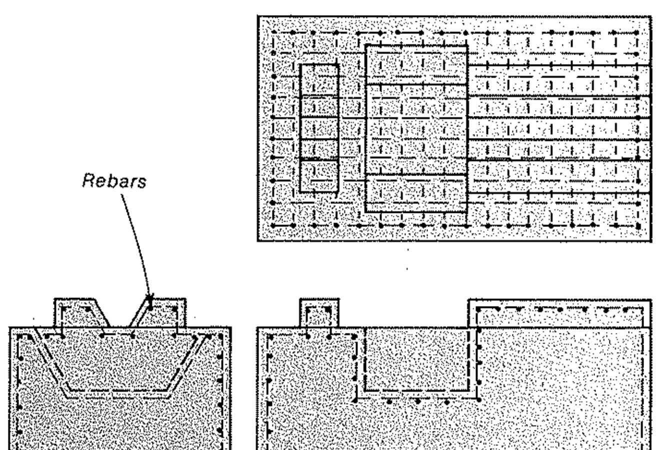
Bar size will vary from No. 4 to No. 7 (numbers represent eighths of an inch) in foundations for 500-6000-hp engines. Longitudinal rods will be No. 7, and sides can be either No. 4 or 5, while bottom bars can be No. 6. Vertical rebars are No. 4 or 5, depending on spacing and size of block. Usually a 12-in. spacing is preferred.

Rebar-rod total sectional area perpendicular to the engine will average 0.13% of sectional area of the concrete. In the plane parallel to the engine crankshaft centerline, the steel sectional area will average 0.07-0.10%.

Rebars should conform to ASTM A305 and A15 intermediate grade. For large foundations, general practice demands that minimum reinforcement for



Transmission of annoying engine-generator set vibration is largely prevented by isolation of set and its heavy block



Reinforcement near surface usually gets 1-3-in. cover. Bent rebars are suitable for pits and outboard bearing abutment any major surface be No. 5 rebars on 12-in. centers, even though the design calls for less. Lapped bars will be at 30 diameters. The figure at the bottom right on the preceding page shows a typical reinforcement design for a V-16 diesel-engine generator drive foundation.

Specifying concrete

Concrete should meet ASTM requirements. Cement should comply with ASTM C150 or C175. Use Type II except where the engine manufacturer allows Type I. Water for concrete-mixing should be free of harmful amounts of solids, alkalis, or organic material. Never use sea water.

Aggregates should comply with ASTM specification C33. Grade the coarse aggregate well, with the largest particles being retained on at least a 1½-in. sieve. Larger particles are acceptable if the material is well graded. Grade fine aggregate within the limits of ASTM C33. An air-entrainment agent is added at the mixer for both Types I and II, with air between 3% and 6%.

The contractor should submit proposed concrete mixtures to the engine or compressor manufacturer for approval. All foundation concrete should have minimum compressive strength on test of 3500 lb/in.^{2} at 28 days. Design strength is 15% in excess of this. Ratio of water to cement should not exceed 6 gal to one 94-lb sack of cement. The contractor should submit test reports of all materials to be used.

Mixing continues until materials are uniformly distributed. Time should be 1 min for the first cubic yard and 15 sec for each additional, with a minimum of 1 min after all materials are in the mixer. For ready-mixed concrete, ASTM C94 gives requirements.

Place concrete as near as possible to its final position, and avoid segregation. Maximum lift is 18 in. A vibrator will help assure that no voids exist. To assure strength and durability of finished concrete, bleed off excess water 1 ft below finished grade for about 1½ hr.

For curing, leave the forms in place for 7 days, and give the block top a cure for the same length of time. This can consist of wet burlap, water ponding, wet sand, or other acceptable methods. During cold weather, provide adequate equipment to prevent freezing. If air temperature is below 40F, all concrete placed should be between 50 and 70F, and the temperature should be held at 70F for 3 days or 50F for 4 days.

For testing, make at least three specimens for each 200 cu yd placed, or for each day's placing. Follow ASTM C39 procedure for 28-day compression tests. Don't apply load to the concrete until it is 28 days old and, if possible, hold off for 60 days, as recommended by the Portland Cement Assn.

Look at chemical grout

Field experience indicates that you should avoid ordinary cement mortar-mix grout for reciprocating machinery. Nonshrinking premixed grout has served for years, and recently a thermosetting inert-filler plastic-resin grout has won attention. These chemical grouts have 2000 lb/in.^{2} tensile strength and 15,000 lb/in.^{2} compressive strength. Linear shrinkage is only 0.00012, and bond strength to steel is 750-1000 lb/in.^{2}

Chemical grouts practically eliminate the natural hazards of grouting, such as incorrect proportions, poor-quality aggregates, and premature hardening. The mix is premeasured and of lab-controlled quality. Hardening rate is slow enough to give plenty of working time. They have high bond strength to metal and concrete, compared with practically none for conventional cement grouts. Chemical resistance is good, and the material will take high impact loading.

Some precautions are necessary in preparing, curing, and handling the chemical grouts. Coat the forms with paste wax, or cover them with polyethylene or waxed paper, to ease removal. Dry the foundation top thoroughly and brush the base flanges clean of rust. During pouring, move the material continuously with grouting sticks or other pushing tools. Below 70F, add liquid accelerators to hasten curing.

Detailed instructions for application of chemical grout usually come from the engine or compressor manufacturer. Although chemical grouts are higher in first cost than premixed grouts, the advantages offset this.

Specially graded iron aggregates in combination with oxidizing, catalytic, and cement-dispersing agents added to approved premixed grouts will offset shrinkage of cement and mortar, reducing the advantages of the chemical grouts over premixed grouts.

Grouts with the additives must be placed continuously and rapidly. Link chains under the base plate and between foundation bolts can work the mix, to aid in flow and reduce voids. The foundation should be roughened and all loose dirt removed. Plug foundation-bolt sleeve openings if removable bolts are used.

Jack pockets in the foundation deserve mention in closing. Recently, there has been a trend to elimination or reduction in the number of these pockets, which have been found to weaken the upper block structure and make grout thickness less uniform. In some cases, toe jacks have instead held the engine about 4 in. above the block, and retracting screws in engine or compressor have allowed the machine to be lowered to grouting height. With two-piece bolt construction, the foundation-boltholes in the base are threaded, and the screw bears down on a removable plate. Where sole plates or rails are under the engine, no pockets are needed. Adjustable chocks support the engine base, and the rails are grouted to the block. ■

New engine can go on an existing block that is in good condition

Occasionally, new engines or compressors are installed to replace existing units. This can be a problem when the foundation is for a different type or manufacturer. If the block is in good shape, however, which means free of cracks or movement, and if it is not oil-saturated from leaks, it may be possible to cap the existing block, as shown at right.

First, a check is necessary to make sure that soil loading from the new machine does not exceed that for the unit to be replaced. Normal procedure then is to remove the upper part of the block. If the bolts equal or exceed the total thread-root area required for the new unit, H-beams or other structural shapes can be welded to the projecting bolt ends.

The new foundation bolts can then be welded to the beam chassis, after which tie rods may be grouted into the other added sections. The upper part is then poured, using a template, similar to normal construction. If soil loading is exceeded, an addition at each end of the block will reduce load to acceptable limits.