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THE DESIGN
AND COST ESTIMATE OF
RESIDENTIAL HOME FOUNDATIONS

Thesis for the Degree of B. S.
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G. C. Enos

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The Design and Cost Estimate of
Residential Home Foundations

A Thesis Submitted to

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THESIS

21

The object of this thesis is to present an approach to the problem of a satisfactory residential home foundation, in a specific, seemingly undesirable location.

It is quite apparent to the engineer, that before the superstructure of a building may be erected, its stability and strength must be protected by a correct foundation. Incorrect foundations permit settling of the entire structure, sometimes unevenly, causing a redistribution of internal stresses which will, in many cases, exceed the maximum for their intended purpose--causing failure.

Now it may seem that this would hold true only for buildings of a large size and weight, that are subject to many and varying loads, and that the ordinary residential homes need little foundation planning or analysis. This would ordinarily be true were it not for the fact that soil varies widely and in many instances is of such a type that a dire problem in foundation stability is presented.

It is because of this fact that this thesis is being written--as an endeavor to solve such a problem.

The circumstances and local color which surround and prompt this thesis are these:

The city of East Lansing is almost entirely residential, and has been growing steadily and should continue to do so for a long time to come. In its expansion, it was discovered

that here and there on the extreme outskirts are lots for sale that are in every sense and respect, except one, extremely desirable for building sites. Only when soil tests were taken was it discovered that these lots, for all their desirability, possessed the worst possible characteristic that land destined for habitation can have--poor subsoil. Borings revealed that a layer of muck and peat extended down anywhere from four to twelve feet before a solid strata of blue clay was reached.

To say to the ordinary layman that the land was much and peat would prompt little comment other than, "swell, I can build my house on it and have a radish garden in back," and illustrates what little concern people have for a subject that is extremely important. As proof of this, let me cite a few true cases of trouble here in East Lansing that have resulted from this ignorance.

There is a house on Abbott Road, quite well out, that is situated on just the type of subsoil under discussion. The owner built it with the initial intention of making himself a garage and so paid no attention whatsoever to the foundation. However, after the garage was built, he decided to erect a few additions and, in time, had an average sized home. This necessitated his lifting the house and building a basement to permit the installation of a heating unit. The entire house was then made to rest on block foundations at each corner. Since the time of its complete erection, he has twice had to raise the superstructure since the basement has perceptibly settled. The living room which runs the full length of the house shows pronounced cracks in the ceiling

and sidewalls, and the kitchen floor, which was added as another separate unit, sloped decidedly down from the house proper.

Beyond the city limits of East Lansing, a group of small, low cost, low type of construction homes were built on a mucky subsoil with no more than ordinary foundation providence. Settlement has since taken place, and basements have cracked permitting the seepage of moisture causing much distress and discomfort to the occupants.

Another case is illustrated by the desire of a family to build a house on a very attractive lot near the one under discussion. Though the lot was muck, they nevertheless were not satisfied with any other location and insisted upon building on that site. The real estate company in selling the lot to them warned them against it, but they persisted. They finally succeeded in obtaining a contractor who thought he could do the job for them. Confidently he went ahead and excavated the muck down to four or five feet where lay a sand loam. This was on one side of the house, and he naturally assumed the other side was the same, so he excavated the same depth all over, and upon still striking muck that ran across one corner, thought nothing of it and made no consideration for it. When he had the foundation finally completed, the corner that he had overlooked settled and he gave up the job. The owner was then obliged to spend extra money and time to remedy this, which, had more knowledge and planning been used, could easily have been avoided.

Still another example is that of a home in East Lansing

on West Grand River where more than ordinary foundation planning was practiced. A floating slab was used in supporting the house on muck subsoil. Details of the design were not available, but in due time the house rose noticeably. It would seem that this was due to conditions within the soil itself. Perhaps there was not sufficient drainage and what is known as frost heave occurred. Or the muck, which is unusually unstable might have shifted to one end under the weight. However, the time for investigation is past, and suffice it to say that though the cause be undetermined, the condition represents an example of proof that more thorough investigation of poor soils is warranted. These instances, then, verify what happens when a home is built on weak subsoil without adequate planning and foundation design.

Therefore, since it has been shown that foundations in the ordinary residential home are an important aspect of the entire structure, especially when bad subsoil is encountered, a specific lot was chosen to be investigated as the site for a fictitious home.

The lot chosen rests on the north east corner of the intersection of Harrison and Northlawn. The real estate company that is charged with selling this lot and others of the same nature which surround it has as yet failed to do so. People are skeptical of buying; the real estate company is casual about selling; and the contractor is wary of building--all because the soil presents such an uncertain problem.

As an incentive, the real estate company has lowered the price to offset the added expense that would be incurred in

designing a suitable foundation.

Good sound lots that are free from design difficulties are held for sale at an average of \$1500, but those that are undesirable because of subsoil conditions are offered at \$850 to \$1000, which allows \$500 to \$650 for extra foundation design.

It would seem then that the ultimate aim of this thesis is not only to profer a design to meet the existing requirements, but also to determine if its cost lies within the provided limits offered by the real estate company thus justifying its construction.

Soil Study

In preparation for the design, the lot had first to be investigated. The blue print on page 8 shows the sub-soil in profile. Augar borings were taken at each prospective corner of the house, one in the center of each side and one in the geometrical center, making a total of nine borings. Profiles of these borings were plotted in sectional form. These profiles show the location of the various soil strata. On the blueprint, these strata are numbered 1, 2, and 3. Number 1 is composed of muck and peat, and each was intermingled with the other. Since peat is a partially decomposed vegetation, it would be prohibitive to place any type of foundation upon it, since in its further decomposition it would shrink, creating voids and a very uncertain but disastrous settlement of the foundation. Therefore it is recommended that this entire strata be excavated in laying the foundation.

Number 2 was a moist mixture of clay and sand of a weak nature. It was soft and porous, and here the difficulty occurs. Since the ordinary type foundation could not be built upon this type of base, it is necessary to design one that could. Of course, this entire strata could be excavated to the depth of Strata # 3, which is firm, solid, blue clay of a very resistant nature. If this was done, a backfill of suitable gravel would have to be made. The question then

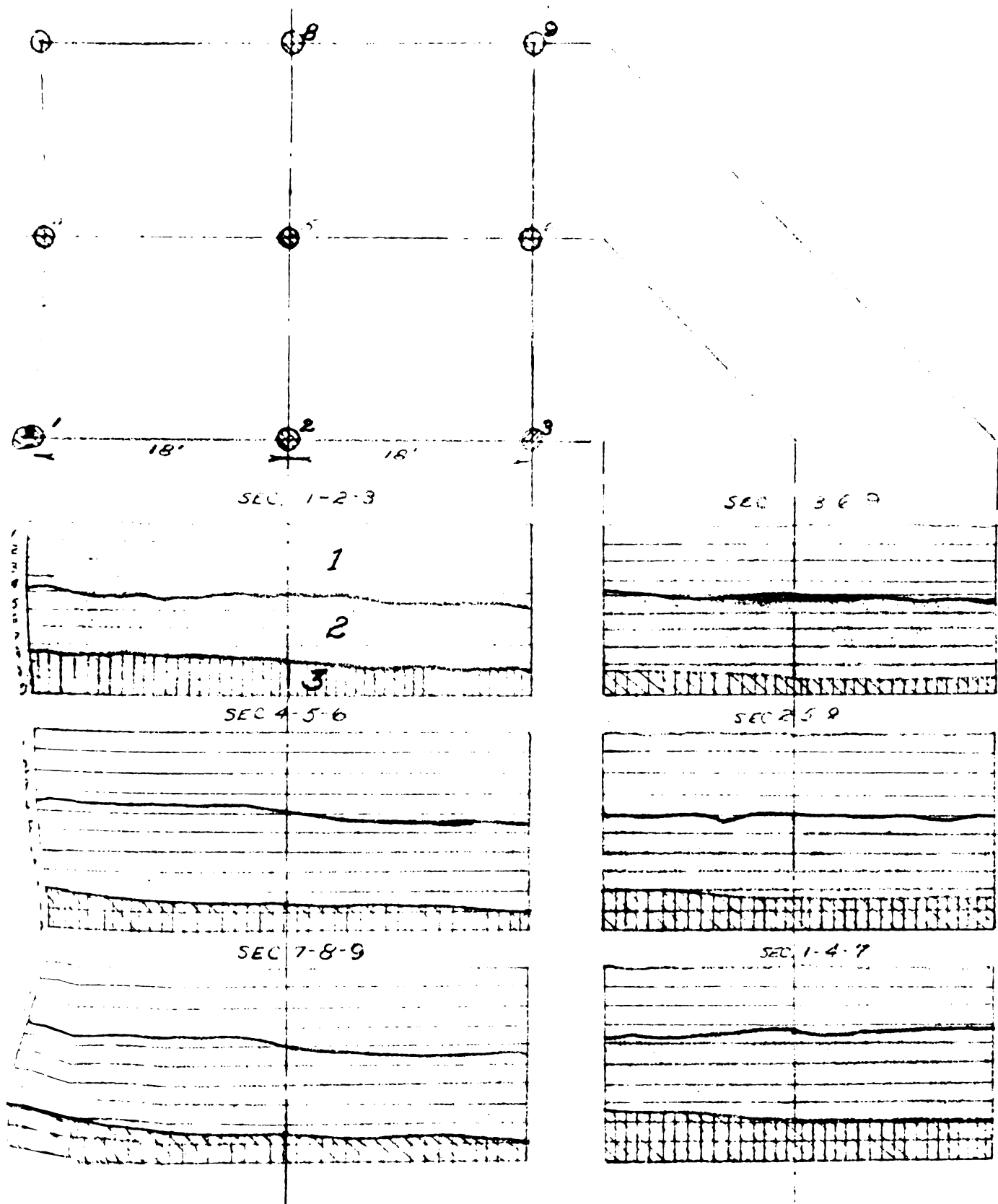
becomes one of economy. Which would be cheaper, and would either fall within the limits provided by the real estate company in their reduction of the lot price?

Since Strata # 2 is of such a weak, undeterminable nature, a very low bearing capacity of 250 pounds per square foot will be assumed in the design of a suitable foundation.

At the time the borings were taken the water plane was quite high and the strata was heavily saturated. Therefore, though drainage will be provided in the foundation design, there will no doubt be initial settlement of the foundation. This would necessitate a design that would settle as a unit.

The most reasonable type of foundation to use in conforming to these conditions would be an entire slab, that would in a manner of speaking, float the entire house on the soil. The slab would then serve both as a foundation and a basement floor.

If initial settlement did occur, it would take place over the entire area and cause no damage. Drainage of the soil beneath the foundation would tend to strengthen the soil, bringing about its maximum density. At this point settlement will cease, if there has been any, and the entire design will reach stability.



D. DIAGRAM SHOWING SECTIONAL PROFILES OF SUBSOIL UNDERLYING HOUSE FOUNDATION

Load Analysis For Slab Foundation

Before designing the actual foundation, the total weight of the house and the manner in which it is distributed to the subsoil must be first computed and analyzed. The assumptions that are made prior to the design are these: that the live loads, with the exception of wind and snow are neglected; that the house shall be of brick; and that the floor beams carry the load to the outside walls which run lengthwise and to the center partition; that in the case of the design for the floating foundation, precast, reinforced concrete beams will be used to span the full 28 feet of the house, thus eliminating a partition in the basement, providing more room and simplifying the design of the slab.

Combined live and dead loads are assumed as follows:

First floor	= 66 lbs. per sq. ft.
Second floor	= 50 " " " "
Roof (plus wind pressure)	= 40 " " " "
Wt. of 8" concrete block wall	= 60 " " " "
Wt. of 10 in. concrete block wall	= 70 lbs. per sq. ft.
Attic	= 20 " " " "

These were taken from a Portland Cement pamphlet and correspond to average values. However, in the case of the first floor, the concrete floor beams were taken into account.

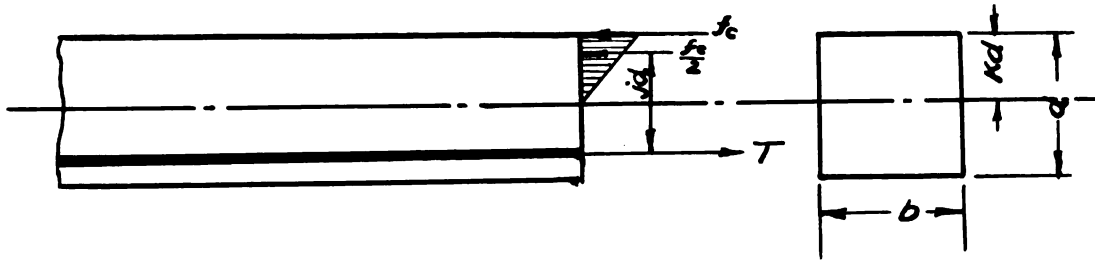
The load on footing per lineal foot:

Attic	= 1,008 sq. ft. x 20 lbs. sq. ft. ÷ perimeter	= 280 lbs.
Second Floor	= 1,008 sq.ft. x 50 lbs.,sq.ft. ÷ perimeter	= 700 #
First Floor	= 1,008 sq.ft. x 66 lbs.sq.ft. ÷ perimeter	= 920 #
Roof load		= 560 #
8 in. wall 18 ft. high	= 18 x 60	= 1080
10 in. wall 8 ft. high	= 8 x 70	= 560
Total		<u>4,100 #</u>

This total is in lbs. per lineal foot.

Now, knowing the total load per lineal foot, and the value to be used for the allowable soil bearing capacity, the slab foundation can be designed.

Development of Internal Moment with Nomenclature



The external bending moment is given as $M_p = \frac{wl^2}{12}$ where

- M_p = Maximum Positive Bending Moment.
- w = Uniformly distributed weight in pounds per lineal foot.
- l = Length of beam, center to center of supports.

The criterion of adequate design demands that the internal moment, which is a function of the internal stress of tension and compression, be equal to the external moment.

In the figure above, the triangle represents the forces of compression. The extreme fiber is subject to the greatest compression which diminishes to zero at the neutral axis.

Nomenclature is designated as follows:

- f_c = Allowable compressive strength of concrete for extreme fiber.
- jd = Moment arm of internal couple.
- kd = Distance from extreme fiber in compression to neutral axis.
- d = Distance from extreme fiber in compression to the center of gravity of the steel in tension.

The average compressive stress over the entire section is $\frac{f_c}{2}$, and because of the triangular manner of distribution, acts at the centroid of the triangle, which is one-third of the altitude measured from the base. The area of the entire section above the neutral axis which is under compression equals $b \times kd$.

The internal moment is therefore

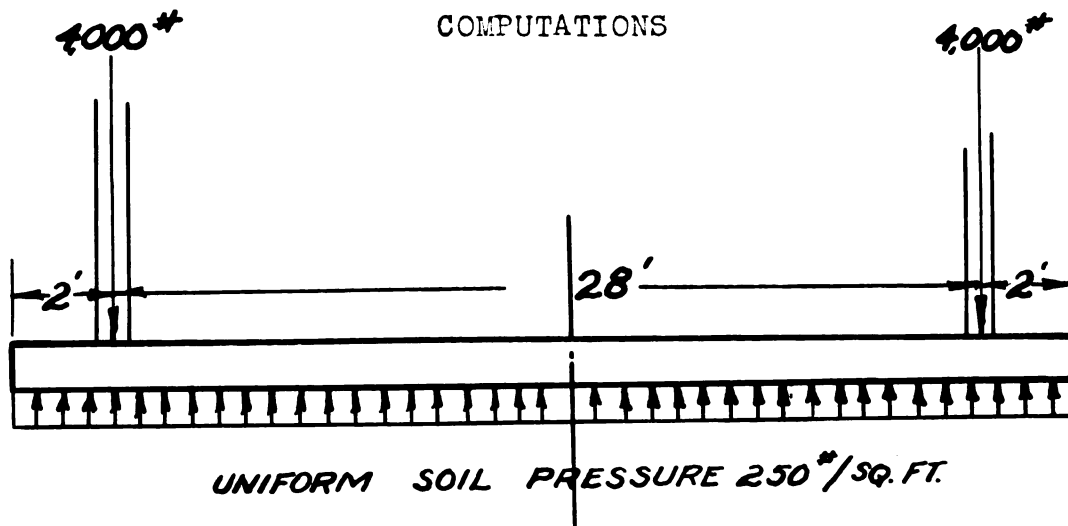
$$\frac{f_c}{2} \cdot jd \cdot b \cdot kd.$$

or $\frac{f_c}{2} \cdot jbk d^2$, where the value of k is given as $\frac{1}{\frac{1}{nf_c} + \frac{f_s}{E_s}}$,

in which f_s = tensile unit stress in longitudinal reinforcement. n = ratio of moduli, or $\frac{E_s}{E_c}$

DESIGN OF FOUNDATION

COMPUTATIONS



The external moment $M_p = \frac{wl^2}{12}$ = the internal moment $M_p = \frac{f_c}{2} j k b d^2$

$$(1) \text{ or } \frac{wl^2}{12} = \frac{f_c}{2} j k b d^2$$

With the allowable soil bearing pressure as 250 lbs. per sq. ft. and a total load of 8,000 lbs., the area needed is:

$$\frac{8,000 \text{ lbs.}}{250 \text{ lbs. sq. ft.}} = 32 \text{ sq. ft.}$$

Since the width of the building is 28 feet, there will be an over lap on each side of two feet and the span will be considered as 28 feet.

$$(2) \text{ Therefore } \frac{wl^2}{12} = \frac{250 \text{ lbs. sq. ft.} (28)^2}{12} = 196000 \text{ in. lbs}$$

$$(3) k = \frac{1}{n f_c} = \frac{1}{15 \times 800} = 3/8$$

$$(4) j = 1 - \frac{k}{3} = 7/8$$

$$(5) f_c = .40 \times 2000 = 800$$

From (1) using values secured from (2), (3), (4), and (5) the equation becomes

$$196,000 \text{ lbs./sq.ft.} = \frac{800}{2} \times 7/8 \times 3/8 \times 12 \times d^2$$

$$\text{whence } d = \sqrt{\frac{196,000 \times 2 \times 64}{21 \times 12 \times 800}} = 12 \text{ ''}$$

In order to protect the steel, an extra amount of concrete will be needed to increase the depth. For most beam cases, this is given as 1 1/2 inches.

$$\text{Thus } h = 12 \text{ } 1\frac{1}{2} = 13.5 \text{ inches.}$$

Having designed the slab to resist bending moment, it will now be necessary to check for shear. With reinforcement, a maximum shear value equal to $.06f_c'$ is allowed.

$$.06 \times 2,000 = 120 \text{ lbs./sq. in.}$$

The allowable unit shearing stress $c = \frac{V}{bjd}$ where V = total shear value.

$$\text{Substituting, } V_c = \frac{4,000}{12 \times 7/8 \times 12} = \frac{4,000}{126} = 31.5 \text{ lbs./sq.in.}$$

Since this is less than the allowable, the beam will resist shear. The amount of reinforcement need is given in terms of area over the end area of the beam, or

$$A_p = \frac{M_p}{f_s j d}, \text{ where } A_p \text{ is the area of the steel.}$$

$$A_p = \frac{196,000}{20,000 \times .875 \times 5.25} = 2.2 \text{ sq. ins.}$$

If 3 one inch round bars were used, the area obtained would be 2.36 sq. ins. which is satisfactory.

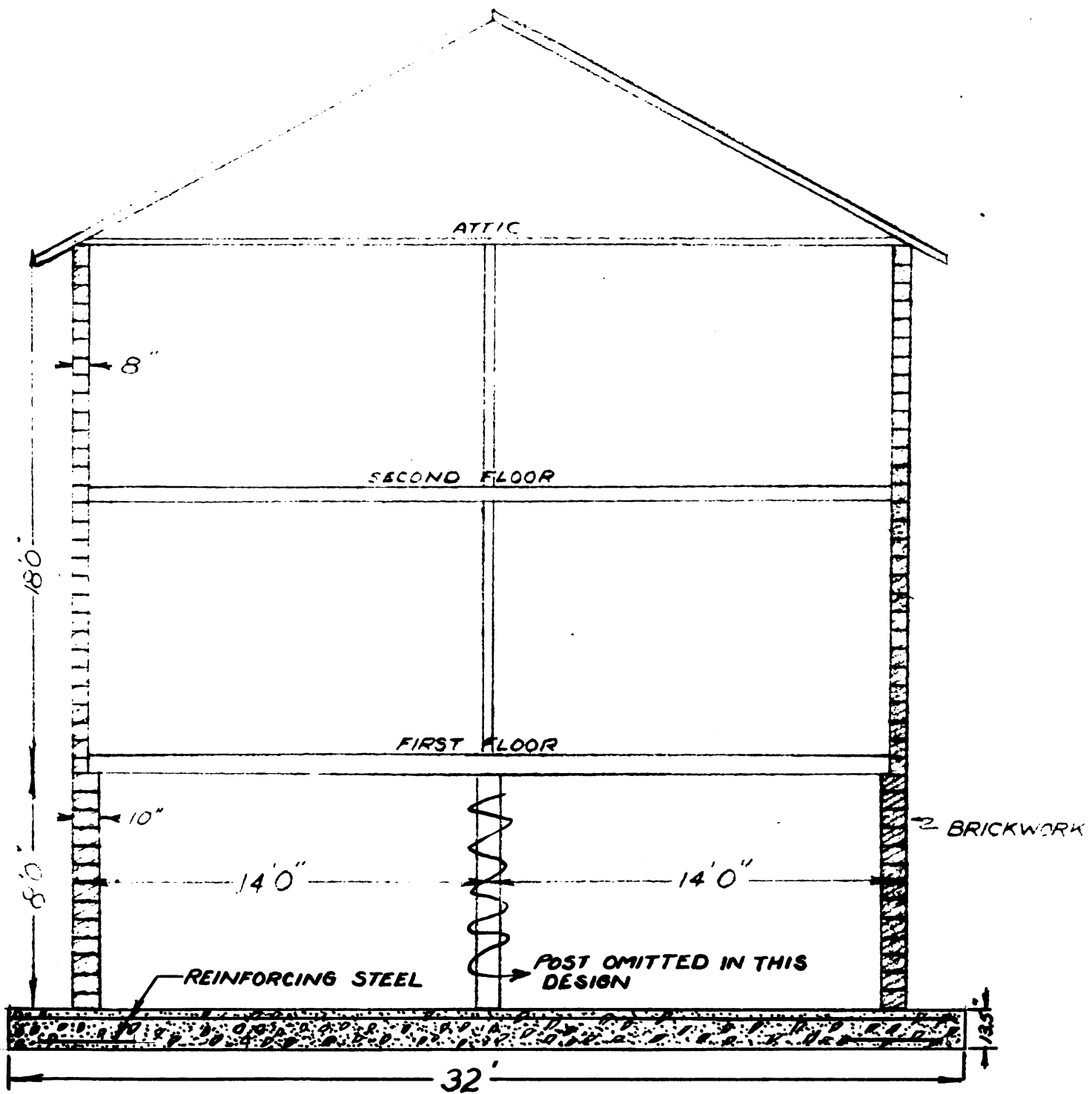
With the design calling for three 1" round bars per foot of width, the spacing tables give for this condition a spacing of four inches between center of bars. The bars will run widthwise of the foundation, coming to within 1 1/2 inches of the edge, which gives a length of 31.75 feet. Since the lengthwise dimension of the foundation is 37.5 feet, this will call for 111 bars, spaced at four inches. Where the tension side reverses directly under the sidewalls, reinforcing bars will also be needed on the opposite side. These will be 2 feet in length and the total number of these required will be 222.

This amounts to 3,968.25 feet of reinforcing and a total of 10,595.23 pounds.

Drainage

It is not the purpose of this thesis to consider drainage from the design standpoint. Realizing that the drainage is necessary in such a case as this, where the land is low, the only concern therefore is that it be included in the cost.

For a house such as this, a 4" drain pipe is ordinarily used to care for the subsurface drainage. Specifications of the Portland Cement Association call for placing a line of tile entirely around the foundation, and then filling the excavation to within a foot of the grade line with a porous material. With this in mind the amount of tile needed if placed 4" from the edge of the slab would be 2 x 37' 10" or roughly 141 feet.



CROSS SECTION OF SLAB FOUNDATION

Design of Foundation(Alternate)

This design will be one such as used in homes which demand only the ordinary type of foundation and would be unnecessary were it not for the fact that it is needed to develop a cost comparison in determining whether it is more economical to use the previous design, or to excavate, back-fill with gravel, and use the design now under discussion.

Thus the object will be primarily to determine the factors affecting cost which is paramountly the amount of concrete needed.

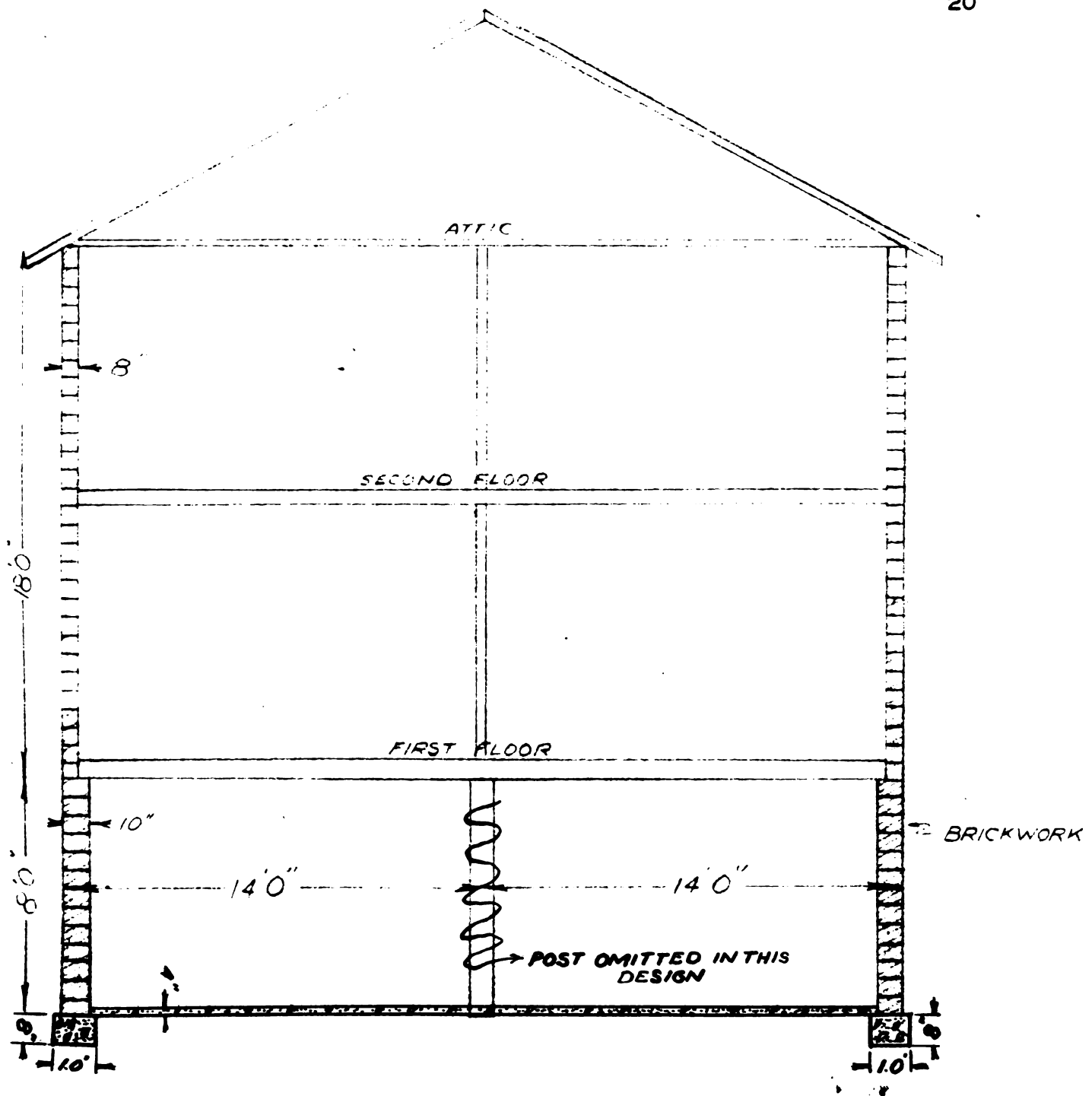
Here, as in the other foundation, the precast, reinforced concrete beams will be used in the first floor to span the entire width of twenty-eight feet, thus eliminating the need for center footings and interior basement columns, creating a more spacious basement. Since these floor beams transmit the loads, ultimately to the two outside walls which run lengthwise, they then need be the only ones figuring into the design. Having once designed the foundations for these, the other two walls will be a duplicate.

Load On Wall Footing Per Lineal Foot

10 in. basement wall, 8 ft. high, 8 x 70 lbs.....=	560 lbs.
8 in. superstructure walls, 18 ft. high, 18 x 60 lbs.=	1,080 lbs.
Roof load... ..=	560 "
First floor = 1,008 sq. ft. x 66 lbs./sq. ft. + 72...=	920 "
Second floor= 1,008 sq. ft. x 50 lbs./sq. ft. + 72...=	700 "
Attic.....= 1,008 sq. ft. x 20 lbs./sq. ft. + 72...=	280 "
Total load per lineal ft.=	4,100 lbs.

Since one square foot of coarse gravel in a loose state will bear about three tons, the amount of soil area needed will be $\frac{4,100}{6} = .69$ sq. ft., which, considering the foundation in terms of lineal feet, would mean a width of .69 feet.

However, it would be better to assume the width of the footing as greater than that of the wall that rests upon it to avoid the possibility of incorrect alignment of brick wall upon foundation and the resulting dissimilarity of stress that might be produced from this. The foundation wall will be constructed one foot in width. Since specifications hold that the footing should be a little more than half as deep as it is wide, eight inches will suffice for the depth. This then provides an area of 1 sq. ft. where only .69 sq. ft. are needed and is added assurance of the adequacy of design.



CROSS SECTION OF ALTERNATE FOUNDATION

The Design of Typical Foundations

Here, for the sake of cost comparison, follows the design of a house that is built on a firmer soil, such as is more often encountered and requires no extra foundation design. The same house is used, but without the precast concrete floor beams for the first floor. This will necessitate post footings and is illustrative of the commoner type. The building is assumed to be located on soft clay soil that has a safe bearing capacity of one ton per square foot.

Combined live and dead loads assumed as follows:

First floor.....	50	pounds per sq. ft.				
Second floor.....	30	"	"	"	"	"
Attic.....	20	"	"	"	"	"
Roof (plus wind pressure).....	40	"	"	"	"	"
Wt. of 8 in. concrete block wall.....	60	"	"	"	"	"
Wt. of 10 in. concrete block wall.....	70	"	"	"	"	"

Load On Wall Footing Per Lineal Foot

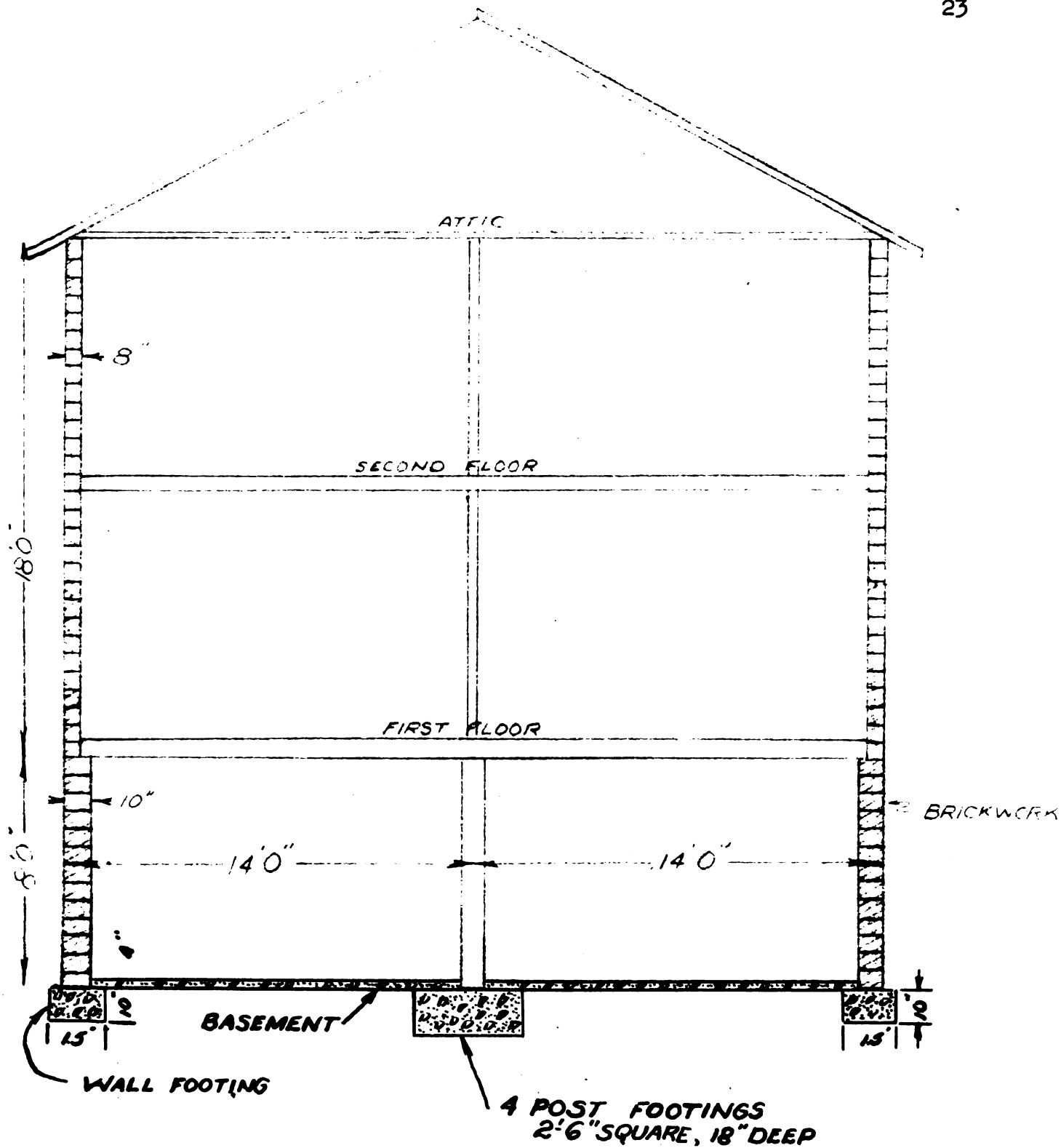
10 in. basement wall, 8 ft. high, 8 x 70 lbs.....=	560 lbs.
8 in. superstructure walls, 18 ft. high, 18 x 60 lbs.=	1,080 lbs.
First and second floor loads, supported on walls,....=	700 "
$\frac{1}{2}$ span, 2 times 7 times 50 lbs.	
Attic floor walls, $\frac{1}{2}$ span, 7 x 20 lbs.....=	140 "
Roof load on footing per lineal foot.....=	280 "
Total load on footing per lineal ft. =	<u>3,760 lbs.</u>

Since one square foot of soft clay soil will bear one ton, approximately one and a half square feet of soil area will be required to carry 3,760 pounds. Therefore, a footing eighteen inches wide is needed. A footing of this width should be about ten inches deep--a little more than half the width.

Load On Each Post Footing

First and second floors, 2 x 7.2 x 14 x 50 lbs.=	10,080 lbs.
Attic Floor, 7.2 x 14 x 20 lbs.....=	2,016 "
Partitions.....=	<u>1,000 "</u>
Total load on each footing =	13,096 lbs.

Dividing 13,096 pounds by 2,000 pounds, the load one square foot will bear, give 6.55 square feet needed to carry the load. A footing 2 feet 8 inches square had a little more than the required area. Therefore, the depth should be eighteen inches.



**CROSS SECTIONAL VIEW OF TYPICAL
FOOTING**

Cost Estimate

With the actual design completed, the next portion of the thesis will be devoted to the estimation of the costs. It would be hard to say which is the better type of design, so the classification will be according to the economy of the design. In figuring the job costs, local current prices are used and run as follows:

Concrete (ready mixed)

For floors----\$7.25 per yard.
 For footings--\$6.75 per yard.
 This includes delivery and placement.

Excavating

If hauled away--\$0.60 per yard.
 Without haul---\$0.40 per yard.

Gravel (hauled)

Washed-----\$1.75 per yard.
 Bank run---\$1.65 per yard.

Tile for drainage

6" pipe---\$0.13 per foot.
 4" pipe---\$0.065 per foot.
 3" pipe---\$0.055 per foot.

Reinforcing steel

\$0.04 per lb.
 \$0.05 per lb. (includes placement).

Since the labor costs have been figured in the price of excavation, placement of steel and concrete, there remains merely the labor involved in the construction of the footings, and foremanship. On the different jobs, the variation is probably negligible so they will be disregarded and the material costs already listed taken as the whole consideration.

Cost Of Slab Type Foundation

Excavation

Cu. yds. of excavation = $\frac{38 \times 30 \times 5}{25} = 212$ cu. yds.

@ \$0.40/yd., cost of excavation = $212 \times \$0.40 = \84.80
 (It is assumed that the excavated portion will be used for fill around the lawn and need not be hauled.)

Concrete

Cu. yds. of concrete = $\frac{32 \times 37.5 \times 13.5}{27 \times 12} = 50.66$ cu. yds.

@ \$7.25/yd., cost of concrete = $\$367.29$

Reinforcing

Lbs. of reinforcing = 10,595.23

@ \$0.05 per lb., cost of reinforcing = $\$528.76$

Drainage

Ft. of 4" drain tile = 141

@ \$0.065 per foot = $\$9.17$

The total approximate price is, as a result of these figures,

\$990.02.

COST OF ALTERNATE FOUNDATION

Excavation

Cu. yds. of excavation = $\frac{38 \times 30 \times 9}{27} = 380$ cu. yds.

@ \$0.40/yd., cost of excavation = $380 \times \$0.40 = \152.00

Backfill

Cu. yds. of backfill = $\frac{38 \times 30 \times 5}{27}$ plus $20\%(\frac{38 \times 30 \times 5}{27}) = 254.4$ cu. yds.

Concrete

Cu. yds. of concrete = $\frac{2 \times 28.16 \times 1 \times .667}{27}$ plus

$\frac{2 \times 34.16 \times 1 \times .667}{27} = 3$ cu. yds.

(This is for footing only.)

@\$6.75/yd., cost of footing = $\$6.75 \times 3 = \20.25

Cu. yds. of concrete for basement = $\frac{36.33 \times 34.33 \times .33}{27} = 15.4$ cu. yds.

@\$7.25/yd. cost of basement = \$111.65

(The basement cost is here included to compensate for the fact that the basement, in the slab type, is a part of the foundation)

The total cost of this foundation = \$729.10.

COST OF TYPICAL FOUNDATION

Excavation

Cu. yds. of excavation = $\frac{38 \times 30 \times 4}{27} = 170$ cu. yds.

@ \$0.40/yd., cost of excavation = \$60.00.

Concrete

Cu. yds. of concrete for footing = $\frac{2 \times 36 \times 1.5 \times .833}{27}$ plus

$\frac{2 \times 28 \times 1.5 \times .833}{27}$ plus $\frac{4 \times 2.667^2 \times 1.5}{27} = 7.45$ cu. yds.

@ \$6.75/yd., cost of footing = $7.45 \times \$6.75 = \50.30 .

Cu. yds. of concrete for basement = $\frac{36.33 \times 34.33 \times .33}{27} = 15.4$ cu yds.

@ \$7.25/cu. yd., cost of basement = \$111.10.

The total cost of this foundation amounts to \$221.40.

CONCLUSION

From the estimation of costs, it is apparent that to build a house on a lot that is largely muck in nature involves considerably more expense than is ordinarily encountered. The total costs are listed as follows:

Slab type foundation.....	\$990.02
Alternate foundation.....	\$729.10
Typical foundation.....	\$221.40

Since the lot under discussion sells for \$650.00 less than the ordinary, the cost of the specially designed foundations should closely approximate this when the cost of a typical foundation is subtracted from them. Doing this, the resulting figures are:

Slab foundation.....	\$768.62
Alternate foundation.....	\$497.70

Thus, from the above, it is apparent that since the Alternate Foundation Design falls below the provided limit, this would be the feasible one to employ. This brings to a point the ultimate objective of this thesis, and affords concluding evidence that extra foundation design, though seemingly more costly, is, in the long run, all things considered, economical as well as necessary.

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