# STATE OF PRACTICE OF GEOTECHNICAL ENGINEERING FOR DESIGN OF CUSTOM HOMES IN THE HOUSTON AREA BETWEEN 1990 AND 2001

**BY**

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Abstract

Practice of geotechnical engineering in the Houston area has been quite interesting during the past decade, depending on the firm, recommendations for design of custom residential homes vary quite a bit. The purpose of this paper is to look at various design approaches and recommendations. This paper summarizes the state of practice for the past decade. Furthermore, the paper recommends procedures to conduct better geotechnical exploration for custom residential projects in the Houston area.

## Introduction

Due to the strong economy, custom homes are being constructed all over the Houston area. Most of these homes are supported on drilled footing type foundations. The focus of this paper is primarily on the design of homes on drilled footings. Many odd shaped homes (U, L shaped or houses with large slabs with notches) are supported on drilled footings. Furthermore, some of these houses have major foundation problems. The purpose of this paper is to review and summarize 99 geotechnical reports in the Houston area, look at various soil types, discussion of risks, heave computations, drilled footing depths, various slab designs, evaluation of environmental conditions, etc. These reports were conducted by 17 different firms located in the Houston area. About 10% of these reports were conducted by Geotech Engineering and Testing. This paper also develops recommendations on how to better conduct geotechnical exploration for custom residential projects in the Houston area.

## Report Research

In order to develop a State of Practice Report, research was conducted to find geotechnical reports for custom homes conducted by various Geotechnical firms in the Houston area. A total of 99 reports were located from GET's library and from various structural engineers throughout the Houston area. These reports were used as a basis of development of our findings.

A map showing where these various soils reports for custom homes were conducted is shown on the site plan, Plate 1 of this paper. As indicated on this map, the concentration of these reports are located within 610 Loop area, near West University, Bellaire, Medical Center, and Kirby area. Furthermore, some of these reports are located along Memorial Drive, Hunters Creek Village, Piney Point Village and Bunker Hill area. A few data points are located outside the Loop.

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Definitions

The data developed during this research study are summarized on Plate 2 of this paper. The definition of each term used in this paper is presented below:

Map I.D. - The map I.D. indicates where a specific soils report was conducted. The map I.D. is key to the site plan, Plate 1.

Year - This indicates the year the soils report was conducted.

Company - This term identifies which company did the soils report. We have companies A, B, C, D, E F, G, H, J, K, L, M, N, O, P, Q, and R, a total of 17.

Report No. - This term designates the report number for each specific company.

Expansive Soils - This term signifies whether or not expansive soils are present at the job site. Expansive soils should have minimum plasticity index of 20 (Ref. 1).

Trees on Site/Site Conditions - This term signifies whether or not trees were present on the site or the firm who conducted the geotechnical report had a Site Condition Section in the report. Sometimes, these soils reports did not even discuss the site conditions. In this case, a dashed line is put in this space for the segment “trees on site/site conditions”.

Effective Plasticity Index (PI) - This column presents the effective plasticity index of the soils developed by BRAB method (Ref. 2).

Discussion of Expansive Soils - This column signifies whether or not the geotechnical report discussed the presence of expansive soils on the site.

Discussion of Risks - This column describes whether or not the geotechnical report discussed various risks that are associated with different types of foundations used for residential foundations built on expansive soils. For example, a structural slab with void would be low risk foundation. However, a slab-on-fill pier foundation will have a higher risk than a structural slab with void type foundation system. A discussion of foundations and risk is given on Plate 3.

Heave Computations - Most of the heave computations for residential projects (if computed at all) were computed by using Potential Vertical Rise method (Ref. 3). This column signifies whether or not a heave computation was computed for the soils report.

**Drilled Footing Depth -** This column signifies what was the recommended pier depth for the specific soils report.

**Structural Slab -** This column signifies whether or not recommendations on a low risk foundation, which is a structural slab with voids/crawl space, was given in a specific geotechnical report. Furthermore, if recommendations on structural slab was given, whether or not recommendations on voids under the floor slabs was given. Therefore, this column signifies whether or not recommendations on structural slabs were present and if recommendations on structural slab were present what was the recommended void size under the floor slab (not under the grade beams).

**Slab-on-Fill -** This column defines whether or not recommendations on slab-on-fill were given in the specific geotechnical report. Furthermore, whether or not a specific fill thickness was given. Some reports presented a very vague fill thickness recommendations.

**Void Box -** This column signifies whether or not recommendations on void boxes were given under the grade beams.

**Drainage -** This column signifies whether or not recommendations on site drainage around the house were given.

**Sprinkler -** This column signifies whether or not recommendations on the presence of a sprinkler system, and their location around the house were given.

**Trees -** This column signifies whether or not recommendations were given on planting a tree next to the foundation. Furthermore, it indicates whether or not recommendations were given on the existing trees next to the foundation.

**Tree Root Removal -** This column signifies whether or not the specific geotechnical report discussed how to treat the tree removal from a specific site. What would be the ramifications of tree removal (heave).

**Construction Monitoring -** This column signifies whether or not the geotechnical report gave specific recommendations on quality control such as conducting of testing including drilled footing observations, concrete testing, earthwork testing by the design geotechnical engineer.

**Review of Foundation Drawings -** This column signifies whether or not the geotechnical engineer of record required that for the foundation drawings be reviewed by him/her to make sure his/her design recommendations are properly interpreted by the structural engineer and other design team members.

Soil
Variability - This column indicates whether or not the geotechnical report indicated that the soils across the site could be variable (from a standpoint of stratigraphy or properties) and there might be a need for design modifications if different soil conditions were encountered.

Analysis of the Data

General. The contents of all of these reports were reviewed and analyzed. The specific recommendations on analysis are presented in the following sections.

Expansive Soils. Many of the reports acknowledged that expansive soils were present on the site. In general when the effective soil plasticity index is above 20, expansive soils are present on the site.

Trees on Site/Site Conditions. About 64% of the reports did not discuss site conditions. Specifically, they did not discuss whether or not trees were on the site or any other site features were located on the property. This is an extremely important part of a geotechnical report where many firms failed to discuss.

Effective Plasticity Index. About 82% of the reports discussed how expansive the soils were at the specific site and gave plasticity index data in the report. About 91% of the sites reviewed had expansive soils on them.

Discussion of Expansive Soils. About 82% of the soils report reviewed did have a discussion of expansive soils within the body of the report.

Discussion of Risks. About 40% of the reports did not have a discussion on risks of using different types foundations. For example, they did not discuss whether a structural slab was better than a slab-on-fill type foundation supported on piers. Again, this is extremely important because, by discussing the risk associated with each different type of foundation, the soils engineer brings in the architect, the structural engineer, the builder and the owner into the decision making process.

Heave Computations. About 74% of the reports did not discuss or calculate the heave. It is not customary to estimate the heave for design of custom residential foundations in the Houston area. One of the reasons for that is, it's not a consensus on the correct method for estimation of heave. Furthermore, it could be expensive. Therefore, most geotechnical consultants use their experience in specifying how much fill is required under the floor slabs to reduce heave on various types of residential foundations. The required fill thickness is usually determined based on the experience and engineering computations of the heave, such as Potential Vertical Rise, PVR (Ref.3).

Drilled Footing Depth. An average pier depth of about 9-ft was specified after reviewing all of these reports. Review of reports from 1996 to 2001 indicated an average pier depth of 10.5-ft. Depth of drilled footings is very important in areas where expansive soils are present. Shallow piers can push up against the grade beams and lift the foundation system, if expansive soils are present at the site. The pier should be placed below the zero movement line. The zero movement line is a line below which no movement (heave) of expansive soils occurs due to weight of the colum of the soils. The piers should be anchored below the zero movement line. Currently, we recommend piers to be placed 12-ft to 15-ft in the Houston area where expansive soils are present.

Structural Slab Recommendations. About 55% of the reports discussed structural slab systems. The other 45% did not discuss it at all. Furthermore if they were discussed, most of them did not specify any kind of a void space that should go under the structural slab system. We believe that there should be a detailed discussion about the use of a structural slab. Furthermore, the recommended void size should be specified. In addition, recommendations on venting of the air underneath the slab should also be discussed. To limit moisture migration through the slab. This is only applicable to a structural slab with a void/crawl space.

Slab-on-Fill. About 97% of the reports did specify a slab-on-fill type foundation or drilled footings system as the type of foundation that should be used to support the structural loads for a typical custom residential foundation. Some of these reports were vague, because they specifically say whether or not fill is required under the floor slabs. The vague statements given did not specify exactly how much fill should be placed under the floor slabs. Majority of the soils reports reviewed indicated the required fill thicknesses of about 24-inches or less. In general, a maximum of 48-inches of select structural fill was specified in the areas where the soils were highly expansive. Our experience indicates that about four-ft of fill will generally reduce the movements to an acceptable level, provided positive environmental controls (drainage, trees, sewer/plumbing leak, etc.) are implemented.

Void Boxes. About 38% of the reports specified the required void box size under the grade beams. Void boxes are recommended by many geotechnical firms in Houston as a way of reducing foundation movements. Expansive soils once swelled up can theoretically move into a void space area (void box) without lifting the grade beams. The discussion on whether or not void boxes should be used under grade beams on residential foundations was conducted by the Foundation Performance Association. It is generally believed that void boxes under grade beams provide channels for water to flow underneath the foundation system. Therefore, the use of them are discouraged. This discussion and idea was developed in 1996.

Drainage. About 93% of the reports discussed that positive drainage was extremely important to the performance of the custom foundation system. Drainage was discussed in a majority of the reports.

Sprinkler Systems. About 86% of the reports reviewed did not discuss the sprinkler system. They did not discuss how the sprinkler system (if used at all) should be placed around the structure to minimize moisture variations and therefore, differential movements.

Trees. About 59% of the reports did discuss trees. Specifically, all the reports that discussed trees, described planting trees next to the foundation system and how they would affect the foundation system. It is understood that if the tree is left in place or planted next to a foundation system, it may cause the soil to shrink and the foundation to settle if clays are present. In all of the reports the word planted was synonymous with trees left in place.

Tree Removal. About 70% of the reports did not discuss the tree root removal in their reports. This is an extremely important section of a report, because tree removal in areas where expansive soils are present, can cause significant heave. Therefore, the reports should address this condition and warn the client. This has not been customary in the Houston area until the year 1995. A detailed study of tree removal and its effect on foundation systems was presented in 1997 by Eastwood and Peverley (Ref. 4).

Construction Monitoring. About 85% the reports suggested following up the design with construction monitoring. Construction monitoring is an important part of any design.

Review of the Plans and Specifications. About 75% of the reports suggested review of the foundation drawings after the design was completed. The review of the foundation design drawings by the geotechnical engineer of the record is important. This review will provide the client with the confidence that the initial designer (architect, structural engineer, owner) understood the soils report and followed the recommendations. It is possible once the drawings are reviewed by the geotechnical engineer of the record, mistakes are found that are reported to the structural engineer. Furthermore, foundation and risks are discussed.

Soil Variability. About 99% of the reports discussed the potential variation of soil stratigraphy and properties across the site. This is a true condition. Subsoils may vary across the lot from a standpoint of stratigraphy and soil properties.

Conclusions and Recommendations

Based on the review of the 99 reports written between 1990 and 2001 for custom homes in the Houston area, the following conclusions and recommendations can be made:

- The soil reports reviewed from 17 companies represent a cross section of the geotechnical firms in the Houston area that do residential work for custom homes.

- Many of these soils reports indicated the presence of expansive soils in the vicinity of the project site. Most of them discussed the presence of expansive soils.

- Only 36% of the reports reviewed discussed site conditions. The rest of the reports did not even address site conditions. The site conditions should be discussed in all reports. Perhaps a picture of the site should be included in the report.

- Foundation types and risks must be discussed.

- A review of the reports indicates an average pier depth of about nine-ft. Pier depths have been increasing in depth in the Houston area since 1995. In the 1970's and early 80's, piers were placed at a depth of about eight-ft. However, due to new understanding of the active zone depth and the effect of trees on foundations, deeper piers have been recommended. However, most geotechnical firms in Houston are not taking account the effect of tree removal in their foundation system. This condition was known to the Houston area after 1995 or 1996. Furthermore, the use of deeper piers is resisted by some designers, builders, owners, etc., because this may add some to the cost of the construction of the foundation system. However, we believe that increasing the depth of the piers by a few feet, the cost of the foundation system should not increase significantly. Furthermore, the risks of putting shallow piers in the area where expansive soils are present are too great. These shallow piers can actually be grabbed by the expansive soils and be pushed against the foundation system, resulting in floor slab heave. Considering that most of the distress of the newly constructed foundations in Houston is heave, the piers should be deep enough to resist uplift due to expansive soils.

- Almost all of the reports discussed the slab-on-fill on drilled footings. However, many of them did not suggest the required fill thickness. We believe that if this type of foundation system is recommended, the fill thickness should be clearly defined. Unfortunately, some soils reports are very vague about the required fill thickness. This has caused foundation problems, because inadequate fill thickness has been placed underneath the floor slabs.

- About one-third of the reports did discuss the use of void boxes underneath the grade beams. Many of them did not. The use of void boxes is a controversial issue today. We do not recommend the use of void boxes under the grade beams.

- Nearly all of the geotechnical reports discussed positive drainage as a major component of foundation design in their report. This should be covered in all reports.

- Not very many reports discussed the presence of sprinkler systems around a house. We believe that the sprinkler system, if used, should be placed all around the house to provide uniform moisture conditions at the edge of the foundation. A non-uniform moisture condition will result in differential movement of the slab and foundation distress.

- The area of the geotechnical reports that requires most improvement is the section that has to do with removal of existing trees. This issue must be further discussed in geotechnical reports. Currently, most geotechnical reports in Houston do not even discuss the effect of tree removal. In the event that a drilled footing foundation system is to be used, minimum boring depths should be 20-ft. Root fiber depth should be logged in the borings. Furthermore, the depth of active zone should be estimated. The effect of tree removal should be clearly discussed in the report.

- Structural engineers who are designing a custom home must make sure the effects of tree removal have been considered in the geotechnical report prior to conducting a design of a residential slab. Some structural engineers blindly disregard this issue and they claim, they followed an erroneous soil report. Knowing the site conditions is also the responsibility of the structural engineer of the record.

- None of the reports reviewed had any suction data or used suction to estimate heave.

- The authors hope that in the future, the concepts, such as the use of suction will be implemented in the design of lightly loaded structures. Currently, most firms in the Houston area do not run suction tests on their soils samples due to costs associated with conducting this type of test and analyzing the data. Due to the extremely competitive nature of doing residential geotechnical work, it is almost impossible to do a detail geotechnical exploration and testing for residential projects. We believe that by providing a minimum standard in conducting geotechnical explorations, more firms will be interested in conducting more advanced and up to date geotechnical explorations and therefore, saving the client from the risks and spending too much money during construction and repair. Having a minimum standard is the only way, we believe, that the practice of design of a custom foundation system for lightly loaded structure in Houston can be improved.

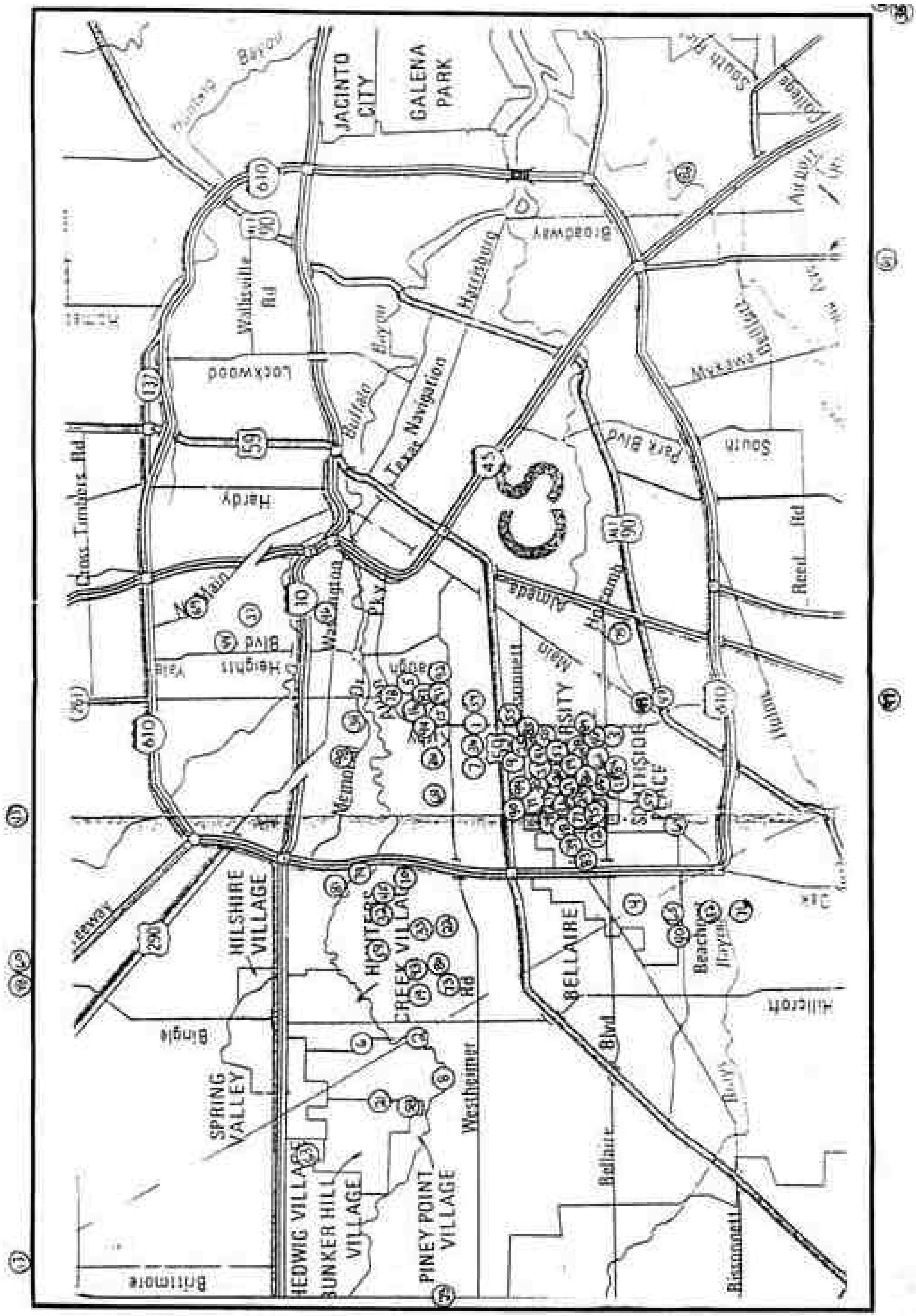
References

1. David Eastwood and Others "Methodology for Foundations on Expansive Clays" Published in December, 1980 Edition of ASCE Journal of Geotechnical Engineering Division.

2. Building Research Advisory Board, National Research Council, "Criteria for Selection and design of Residential Slabs on Grounds," National Academy of Science Publication 1571, 1968.

3. "Method for Determining the Potential Vertical Rise, PVR," State Department of Highways and Public Transportation, Test Method Tex 124-E, Austin, Texas.

4. D. Eastwood and D. Peverley "Design of Foundations with Trees in Mind", presented before the ASCE, Texas Section, Spring Meeting in Houston, April 1997.




Site Plan **Plate 1**

**STATE OF PRACTICE, RESIDENTIAL FOUNDATIONS 1990 THROUGH 2001**

| Map ID | Year | Company | Report No. | Expansive Soils? | Trees on Site? | Effective Plasticity Index (PI) | Discussion of Expansive Soil? | Discussion of Risks | Heave Computation | Drilled Footing Depth, ft. | Structural Slab | | Slab on Fill | | Void Box Size, in. | Recommendations on | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Recommendations | Void Size, in. | Recommendations | Fill Thickness, in. | | Drainage | Sprinkler | Trees | Tree Root Removal | Construction Monitoring | Review of Foundation Drawings | Soil Variability |
| 1 | 1990 | J | 209-90E | Yes | -- | 37 | No | No | No | 8 | No | -- | Yes | 12 | 4 | Yes | No | No | No | Yes | Yes | Yes |
| 2 | 1990 | K | 90-182G | Yes | -- | 40 | Yes | Yes | I | 8 | Yes | 4 | Yes | 48 | -- | Yes | Yes | Yes | No | Yes | Yes | Yes |
| 3 | 1990 | H | G90-330 | Yes | -- | 49 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 4 | 1991 | B | 91G1024 | Yes | Yes | 45 | Yes | Yes | No | 8-9 | Yes | -- | Yes | 18 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 5 | 1991 | H | G91-407 | Yes | -- | 20 | No | No | No | 6 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 6 | 1991 | H | G91-157 | Yes | -- | 24 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 7 | 1991 | H | G91-410 | Yes | -- | 41 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 8 | 1991 | L | 191031 | Yes | -- | 40 | Yes | Yes | No | 8 | Yes | 6 | Yes | 24 | -- | Yes | No | No | No | Yes | Yes | |
| 9 | 1991 | H | G91-126 | Yes | -- | 37 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 10 | 1991 | N | 286-05230-1 | Yes | -- | 60 | Yes | Yes | Yes | 10 | Yes | -- | Yes | 24 | -- | Yes | Yes | Yes | No | Yes | Yes | Yes |
| 11 | 1991 | H | G91-252 | Yes | -- | 59 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 12 | 1991 | L | 191074 | Yes | -- | 40 | Yes | Yes | No | 8 | No | -- | Yes | 24 | 6 | No | No | No | No | No | No | No |
| 13 | 1991 | G | 9104-1002 | No | Yes | 15 | No | No | No | -- | No | -- | Yes | -- | -- | Yes | No | No | No | No | No | Yes |
| 14 | 1991 | P | HE-91-077 | Yes | -- | 50 | Yes | Yes | No | 10 | No | -- | Yes | 24 | -- | Yes | No | Yes | Yes | Yes | No | Yes |
| 15 | 1992 | A | 92-459E | Yes | Yes | 35 | Yes | Yes | No | 10 | Yes | 6 | Yes | 24 | 4 | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 16 | 1992 | B | 92G2028 | Yes | Yes | 41 | Yes | yes | No | 9 | Yes | -- | Yes | 18-24 | 4 | Yes | No | yes | yes | Yes | Yes | Yes |
| 17 | 1992 | G | 9211-1026 | Yes | -- | 40 | Yes | Yes | No | 8 | Yes | -- | Yes | 24 | -- | No | No | No | No | No | No | Yes |
| 18 | 1992 | H | G92-248 | Yes | -- | 65 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 19 | 1992 | K | 92-107G | Yes | -- | 25 | Yes | No | No | 8 | Yes | 4 | Yes | 18 | 4 | No | No | No | No | Yes | Yes | Yes |
| 20 | 1992 | J | 116-92E | Yes | -- | 35 | No | No | No | 7 | No | -- | Yes | 12 | -- | Yes | No | No | No | Yes | Yes | Yes |
| 21 | 1992 | H | G92-215 | No | -- | 19 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 22 | 1992 | F | 9236-1 | Yes | -- | 38 | Yes | No | I | 8 | No | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 23 | 1992 | H | G92-289 | Yes | -- | 41 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 24 | 1992 | J | 180-92E | Yes | -- | 40 | No | No | No | 7 | No | -- | Yes | 12 | 4 | Yes | No | No | No | Yes | Yes | Yes |
| 25 | 1992 | G | 9206-1017 | Yes | -- | 42 | Yes | Yes | No | 8 | Yes | -- | Yes | 18 | 3 | Yes | No | No | No | Yes | No | Yes |
| 26 | 1992 | L | 192057 | Yes | -- | 47 | Yes | No | No | 8 | No | -- | Yes | 24 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 27 | 1992 | J | 209-92E | Yes | -- | 41 | No | No | No | 8 | No | -- | Yes | 12 | 4 | Yes | No | No | No | Yes | Yes | Yes |
| 28 | 1992 | F | 92948-1 | Yes | No | 32 | Yes | Yes | I | 8 | No | -- | Yes | I | -- | Yes | No | No | Yes | Yes | Yes | Yes |
| 29 | 1992 | M | 309-92 | No | -- | 19 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 30 | 1992 | J | 210-92E | Yes | -- | 42 | Yes | No | No | 10 | No | -- | Yes | 24 | 4 | Yes | No | No | No | Yes | No | Yes |
| 31 | 1992 | K | 92-266G | Yes | -- | 32 | Yes | Yes | I | 8 | Yes | -- | Yes | 20 | 6 | Yes | No | No | No | Yes | Yes | Yes |
| 32 | 1992 | H | G92-583 | Yes | -- | 51 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 33 | 1992 | M | 323-92 | Yes | -- | 45 | Yes | No | I | 8 | No | -- | Yes | 12 | 4 | Yes | No | No | No | No | No | Yes |
| 34 | 1992 | H | G92-122 | Yes | No | 51 | Yes | yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 35 | 1993 | G | 9310-1011 | Yes | -- | 38 | Yes | Yes | No | 6-11 | Yes | -- | Yes | 24 | -- | No | No | No | No | No | No | Yes |
| 36 | 1993 | B | 93G3867 | Yes | Yes | 42 | Yes | Yes | No | 9 | Yes | -- | Yes | 24 | -- | Yes | No | Yes | No | Yes | Yes | Yes |
| 37 | 1993 | H | G93-211 | No | -- | 11 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 38 | 1993 | F | 93934-1 | Yes | No | 26 | Yes | No | Yes | 6 | No | -- | Yes | -- | -- | Yes | No | No | No | No | No | Yes |
| 39 | 1993 | B | 92G3274 | Yes | No | 67 | Yes | Yes | No | 9 | Yes | -- | Yes | 30 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 40 | 1993 | B | 93G3921 | Yes | Yes | 48 | Yes | Yes | No | 9 | Yes | -- | Yes | 18 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 41 | 1993 | B | 93G3665 | Yes | Yes | 40 | Yes | Yes | No | 9 | Yes | -- | Yes | 24 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 42 | 1993 | B | 93G4082 | Yes | No | 40 | Yes | Yes | No | 9 | Yes | -- | Yes | 18-24 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 43 | 1993 | H | G93-577 | No | -- | 8 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 44 | 1993 | B | 93G3471 | Yes | Yes | 35 | Yes | Yes | No | 9 | Yes | -- | Yes | 18 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 45 | 1993 | G | 9311-1021 | Yes | -- | 56 | Yes | Yes | No | 8 | Yes | -- | Yes | 24 | -- | Yes | No | No | No | Yes | Yes | Yes |
| 46 | 1993 | B | 93G3689 | Yes | No | 32 | Yes | Yes | No | 9 | Yes | -- | Yes | 24 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 47 | 1993 | J | 275-93E | Yes | -- | 45 | Yes | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | No | Yes |
| 48 | 1993 | J | 284-93E | Yes | -- | 21 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | No | |
| 49 | 1993 | J | 118-93E | Yes | -- | 41 | Yes | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 50 | 1993 | J | 127-93E | Yes | -- | 39 | Yes | No | No | 8 | No | -- | Yes | 12 | 4 | Yes | No | No | No | Yes | No | Yes |
| 51 | 1993 | M | 142-93 | Yes | -- | 32 | Yes | Yes | No | 8-10 | Yes | -- | Yes | 12 | -- | Yes | No | No | No | Yes | Yes | Yes |
| 52 | 1993 | J | 223-93E | Yes | -- | 25 | Yes | No | No | 6 | No | -- | Yes | 12 | -- | Yes | No | No | No | Yes | Yes | Yes |
| 53 | 1993 | N | 286-35056 | Yes | -- | 48 | Yes | No | Yes | -- | -- | -- | -- | 24-36 | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 54 | 1993 | F | 93832-1 | Yes | -- | 28 | Yes | No | I | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | No | Yes |
| 55 | 1993 | C | 93-031 | Yes | -- | 70 | Yes | Yes | No | 10 | Yes | -- | Yes | 36 | 6 | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 56 | 1993 | A | 93-347E | Yes | Yes | 42 | Yes | Yes | No | 10-13 | Yes | 6 | Yes | 30 | 4 | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 57 | 1994 | B | 94G4517 | Yes | No | 55 | Yes | Yes | No | 9-10 | Yes | -- | Yes | 24 | -- | Yes | No | Yes | No | Yes | Yes | Yes |
| 58 | 1994 | H | G94-359 | No | -- | 16 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 59 | 1994 | B | 94G4981 | Yes | Yes | 37 | Yes | No | No | 9-10 | No | -- | Yes | 18 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 60 | 1994 | G | 9404-1003 | Yes | -- | 27 | Yes | Yes | No | 6 | Yes | -- | Yes | 18 | 3 | Yes | No | Yes | No | Yes | No | Yes |
| 61 | 1994 | F | 94736-1 | No | -- | 16 | Yes | No | No | 7 | No | -- | Yes | -- | -- | Yes | No | No | No | No | No | Yes |
| 62 | 1994 | G | 9405-1017 | Yes | -- | 37 | Yes | No | No | 8 | Yes | -- | Yes | 18 | 3 | No | No | No | No | No | No | Yes |
| 63 | 1994 | B | 94G4518 | Yes | No | 26 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | Yes | No | Yes | Yes | Yes |
| 64 | 1994 | B | 94G4511 | Yes | No | 40 | Yes | Yes | No | 9-10 | Yes | -- | Yes | 18 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 65 | 1994 | B | 94G5066 | Yes | No | 51 | Yes | Yes | No | 9-10 | Yes | -- | Yes | -- | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 66 | 1994 | H | G94-403 | Yes | -- | 36 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 67 | 1994 | H | G94-478 | Yes | -- | 55 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 68 | 1994 | B | 94G4728 | Yes | -- | 40 | Yes | Yes | No | 9 | Yes | -- | Yes | 24 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 69 | 1994 | B | 94G4865 | Yes | No | 26 | No | No | No | 9-10 | No | -- | Yes | -- | -- | Yes | No | Yes | No | Yes | Yes | Yes |
| 70 | 1994 | E | 94G1204 | Yes | Yes | 28 | Yes | Yes | No | 8-9 | Yes | -- | Yes | 18 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 71 | 1994 | A | 94-034E | Yes | -- | 45 | Yes | Yes | No | 12 | Yes | 8 | Yes | 36 | 6 | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 72 | 1995 | E | 95G1507 | Yes | -- | 29 | Yes | Yes | No | 8-9 | No | -- | Yes | -- | -- | Yes | No | Yes | No | Yes | No | Yes |
| 73 | 1995 | B | 95G6719 | Yes | -- | 53 | Yes | No | No | 7-8 | No | -- | Yes | 24 | -- | Yes | No | Yes | No | Yes | Yes | Yes |
| 74 | 1995 | B | 95G6976 | Yes | No | 21 | No | No | No | 7-8 | No | -- | Yes | -- | -- | Yes | No | Yes | No | Yes | Yes | Yes |
| 75 | 1995 | F | 95749-1 | Yes | No | 50 | Yes | Yes | Yes | 8 | Yes | -- | Yes | 12 | -- | Yes | No | Yes | No | No | No | Yes |
| 76 | 1995 | F | 951184-1 | Yes | No | 28 | Yes | No | Yes | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | No | No | Yes |
| 77 | 1995 | H | G95-221 | Yes | -- | 55 | Yes | Yes | Yes | 8 | Yes | -- | Yes | I | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 78 | 1995 | E | 95G1486 | Yes | -- | 23 | No | No | No | 7 | No | -- | Yes | -- | -- | Yes | No | Yes | No | Yes | Yes | Yes |
| 79 | 1995 | A | 95-546E | Yes | -- | 45 | Yes | Yes | No | 11 | Yes | 6 | Yes | 36 | 4 | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 80 | 1996 | B | 96G7137 | Yes | No | 50 | Yes | No | No | 8-9 | No | -- | Yes | 24 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 81 | 1996 | H | G96-205 | Yes | -- | 26 | Yes | Yes | NO | 8 | Yes | -- | Yes | -- | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 82 | 1996 | F | 96995-1 | Yes | -- | 26 | Yes | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | No | No | Yes |
| 83 | 1996 | F | 96778-1 | Yes | -- | 35 | Yes | No | Yes | 8 | No | -- | Yes | 12 | -- | Yes | No | No | No | No | No | Yes |
| 84 | 1996 | F | 96935-1 | Yes | -- | 30 | Yes | No | Yes | 8 | No | -- | Yes | 12 | -- | Yes | No | No | No | No | No | Yes |
| 85 | 1996 | H | G96-597 | Yes | -- | 30 | No | No | No | 8 | No | -- | Yes | -- | -- | Yes | No | No | No | Yes | Yes | Yes |
| 86 | 1996 | A | 96-658E | Yes | Yes | 71 | Yes | Yes | No | 15 | Yes | 8 | Yes | 48 | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 87 | 1997 | E | 97G3078 | Yes | -- | -- | Yes | Yes | No | 10 | Yes | -- | Yes | 30 | -- | Yes | No | Yes | Yes | Yes | Yes | Yes |
| 88 | 1997 | N | 286-75169 | Yes | -- | 40 | Yes | Yes | Yes | 8 | No | -- | -- | -- | 24 | Yes | Yes | Yes | No | Yes | Yes | Yes |
| 89 | 1997 | A | 97-418E | Yes | Yes | 52 | Yes | Yes | No | 15 | Yes | 6 | Yes | 48 | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 90 | 1998 | A | 98-410E | Yes | Yes | 58 | Yes | Yes | No | 15 | Yes | 8 | Yes | 48 | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 91 | 1999 | F | 99235-1 | Yes | Yes | 31 | Yes | Yes | Yes | 9 | Yes | -- | Yes | 24 | -- | Yes | No | Yes | Yes | No | No | Yes |
| 92 | 1999 | E | 99G5448 | Yes | No | 55 | Yes | Yes | No | 10 | No | -- | Yes | 30 | -- | Yes | No | Yes | No | Yes | No | Yes |
| 93 | 1999 | E | 99G5098 | Yes | Yes | 28 | Yes | Yes | No | 9 | Yes | -- | Yes | 24 | 4 | Yes | No | Yes | No | Yes | Yes | Yes |
| 94 | 1999 | E | 99G5225 | Yes | No | 41 | Yes | Yes | No | 8 | No | -- | Yes | 24 | -- | Yes | No | Yes | No | Yes | No | Yes |
| 95 | 1999 | A | 99-504E | Yes | Yes | 55 | Yes | Yes | No | 12 | Yes | 8 | Yes | 48 | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 96 | 2000 | C | 00-137 | Yes | -- | -- | Yes | No | No | 10 | Yes | -- | Yes | -- | -- | No | No | No | No | Yes | Yes | Yes |
| 97 | 2000 | D | 2K-04 | No | -- | 10 | Yes | Yes | No | 10 | Yes | 4 | Yes | 18 | -- | No | No | No | No | Yes | Yes | Yes |
| 98 | 2000 | A | 00-822E | Yes | Yes | 32 | Yes | Yes | No | 15 | Yes | 8 | Yes | 42 | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| 99 | 2001 | A | 01-009E | Yes | Yes | 48 | Yes | Yes | No | 15 | Yes | 8 | Yes | 48 | -- | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

NOTE:I. Misleading recommendations on heave computation and fill thickness.

Plate 2

# FOUNDATIONS AND RISKS

Many lightly loaded foundations are designed and constructed on the basis of economics, risks, soil type, foundation shape and structural loading. Many times, due to economic considerations, higher risks are accepted in foundation design. Most of the time, the foundation types are selected by the owner/builder, etc. It should be noted that some levels of risk are associated with all types of foundations and there is no such thing as a zero risk foundation. All of these foundations must be stiffened in the areas where expansive soils are present and trees have been removed prior to construction. It should be noted that these foundations are not designed to resist soil and foundation movements as a result of sewer/plumbing leaks, excessive irrigation, poor drainage and water ponding near the foundation system. The followings are the foundation types typically used in the area with increasing levels of risk and decreasing levels of cost:

| FOUNDATION TYPE | REMARKS |
|---|---|
| Structural Slab with Piers | This type of foundation (which also includes a pier and beam foundation with a crawl space) is considered to be a low risk foundation if it is built and maintained with positive drainage and vegetation control. A minimum crawl space of six-inches or larger is required. Using this foundation, the floor slabs are not in contact with the subgrade soils. This type of foundation is particularly suited for the area where expansive soils are present and where trees have been removed prior to construction. The drilled footings must be placed below the potential active zone to minimize potential drilled footing upheaval due to expansive clays. In the areas where non-expansive soils are present, spread footings can be used instead of drilled footings. |
| Slab-On-Fill Foundation Supported on Piers | This foundation system is also suited for the area where expansive soils are present. This system has some risks with respect to foundation distress and movements, where expansive soils are present. However, if positive drainage and vegetation control are provided, this type of foundation should perform satisfactorily. The fill thickness is evaluated such that once it is combined with environmental conditions (positive drainage, vegetation control) the potential vertical rise will be reduced. The structural loads can also be supported on spread footings if expansive soils are not present. |
| Floating (Stiffened) Slab Supported on Piers. The Slab can either be Conventionally-Reinforced or Post-Tensioned | The risk on this type of foundation system can be reduced sizably if it is built and maintained with positive drainage and vegetation control. Due to presence of piers, the slab cannot move down. However, if expansive soils are present, the slab may move up, behaving like a floating slab. In this case, the steel from the drilled piers should not be dowelled into the grade beams. The structural loads can also be supported on spread footings if expansive soils are not present. |
| Floating Super-Structural Slab Foundation (Conventionally-Reinforced or Post-Tensioned Slab) | The risk on this type of foundation system can be reduced significantly if it is built and maintained with positive drainage and vegetation control. No piers are used in this type of foundation. Many of the lightly-loaded structures in the state of Texas are built on this type of foundation and are performing satisfactorily. In the areas where trees have been removed prior to construction and where expansive clays exists, these foundations must be significantly stiffened to minimize the potential differential movements as a result of subsoil heave due to tree removal. The beauty of this foundation system is that as long as the grade beams penetrate a minimum of six-inches into the competent natural soils or properly compacted structural fill, no compaction of subgrade soils are required. The subgrade soils should; however, be firm enough to support the floor slab loads during construction. The structural engineer should design the floor slabs such that they can span in between the grade beams. The subsoils within which the grade beams are placed must have a minimum shear strength of 1000 psf and a minimum degree of compaction of 95 percent standard proctor density (ASTM D 698-91) at a moisture content within ±2% optimum moisture content. |
| Floating Slab Foundation (Conventionally-Reinforced or Post-Tensioned Slab) | The risk on this type of foundation can be reduced significantly if it is built and maintained with positive drainage and vegetation control. No piers are used in this type of foundation. Many of the lightly-loaded structures in the state of Texas are built on this type of foundation and are performing satisfactorily. In the area where trees have been removed prior to construction and where expansive clays exists, these foundations must be significantly stiffened to minimize the potential differential movements as a result of subsoil heave due to tree removal. However, foundation tilt can still occur even if the foundation system is designed rigid. |

The above recommendations, with respect to the best foundation types and risks, are very general. The best type of foundation may vary as a function of structural loading and soil types. For example, in some cases, a floating slab foundation may perform better than a drilled footing type foundation.

Plate 3