PDHonline Course G421 (3 PDH)

Basics on Forensic Engineering - Part IV

Instructor: Ruben A. Gomez, PE

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

Basics on Forensic Engineering Part IV

Ruben A. Gomez, P.E.

1.0 Introduction

This course is part of a series in which all parts are interconnected in a certain order and it would be most beneficial if the reader has already gone through Parts I through III in order to derive complete and maximum benefits.

We have indicated already in the prior parts all the many qualities that are desirable in the forensic engineer, but none is as desirable to determine his competency than that of possessing high ethical standards. Ethical and moral principles are put to the test more often than in any other endeavor. Since the forensic engineer is in the position to adversely affect the assets and reputation of others, his role should not be taken lightly. He must be able to maintain objectivity and impartiality in his seeking of the facts conducive to the truth. In this case, such objectivity also implies the ability to discard all pre-conceived notions and "gut feelings" when the facts do not support the preliminary hypotheses. In sum, forensic engineering is not a profession for "stubborn know-it-alls", but for those willing to examine all the possibilities before they can reach reasonable conclusions.

2.0 Business Mentality

We have heard many engineers saying that if it was entirely up to them, they would devote all their time to engineering rather than to the business end of it. However, being a good businessman is as important as being a good engineer because in order to keep a continuous and healthy practice he must work ahead in developing ideas and a robust portfolio.

Call often for staff meetings, show them where the mistakes have been made and what to do to improve performance. Listen to the feedback from your personnel. Be attentive with your billing procedures, the final bill should always accompany the report. Review your account receivables often with your accountant or bookkeeper.

The search for new sources of business is important, but also as important is the effort to keep your current clients satisfied and fully engaged by keeping them well informed and providing you with the feedback necessary for your performance to be constantly on an improving trend.

Here is an example of what to do in keeping your client aware of your presence and your desire to give him more for his money. This is a letter which could fulfill those objectives:

Dear Mr. Wainwright,

We enjoyed and appreciated the opportunity to work recently with you on the above referenced case. We wish you to know that our goal is to deliver the highest quality engineering performance that is possible. To accomplish such proposition, we would like to have your straightforward feedback.

Please take a few minutes to gives us your comments on the enclosed evaluation form. Thank you for taking the time to let us know how we can improve our serving you.

Truly yours,

Forensic Engineering Corporation (FEC)

Julius Palin
Marketing Vice-President

CLIENT'S EVALUATION FORM
(please circle your level of satisfaction)

	poor									best
1. Did FEC's personnel keep you informed on the progress of the case?	1	2	3	4	5	6	7	8	9	10
2. Were you verbally notified of the preliminary findings in a timely manner?	1	2	3	4	5	6	7	8	9	10
3. Were you verbally notified of the final conclusions on the case prior to receiving the final written report?	1	2	3	4	5	6	7	8	9	10
4. Did you receive the report when promised?	1	2	3	4	5	6	7	8	9	10
5. Did the report address the questions you asked?	1	2	3	4	5	6	7	8	9	10
6. Were the conclusions presented in a clear and specific manner?	1	2	3	4	5	6	7	8	9	10
7. Was there sufficient photographic coverage provided?	1	2	3	4	5	6	7	8	9	10
8. Did the photos clarify and document the case properly?	1	2	3	4	5	6	7	8	9	10

9. Did FEC's personnel keep you well informed about work progress, cost estimate and budgeting? 1 2 3 4 5 6 7 8 9 10

10. Did the final invoice fall within the limits established? 1 2 3 4 5 6 7 8 9 10

11. Were our communications handled in a cordial manner? 1 2 3 4 5 6 7 8 9 10

12. Were your final comments addressed in a proper manner? 1 2 3 4 5 6 7 8 9 10

13. Feedback & Comments:

____
____
____
____
____
____
____

Date:

Prepared by:

3.0 The Formal Written Report

On Part II we referred to the report in a preliminary and cursory basis, this time we will cover that matter in more detail.

Unless requested by the client to be withheld, a written report is the culmination of the forensic engineer's work and generally should follow a uniform format, that way it will provide the client with a standard product which could be more easily reviewed and better understood.

This is the recommended format adopted by FEC in 1990:

1. Title Sheet
2. Table of Contents
3. Introduction
4. Background
5. Investigation
6. Analysis & Discussion
7. Conclusions
8. Recommendations (when applicable)
9. Appendices

TITLE SHEET

This page should state the title of the case, name of client (provided it is not objected), date of loss (DOL), date completed, control number, the name of the author and his title.

TABLE OF CONTENTS

The table of contents lists the different parts of the report following the above or similar sequence.

INTRODUCTION

Part of the introduction would be the date of request, the task asked by the client and the questions to be addressed by the forensic engineer as part of the assigned investigation.

BACKGROUND

This is an important foundation for the investigation, it should tell a brief story of what the case is about. Such information should be an attempt to set the stage and a description of the known conditions that existed at the time the investigation was first requested by the client, as well as the facts as known by those identified parties who asserted and supported them. All available information should be considered for as long as the sources are properly identified.

A well assembled case background should not fall short on describing in detail the *how, who, when and where*, in such a way to build the foundation for a well examined and investigated case.

INVESTIGATION

This section must contain a narrative describing exactly what was done by the investigating forensic engineer and his team (if any). The names of those persons who witnessed or assisted in the course of the investigation should be identified and recorded on the report. Any testing laboratory, either in-house or out-house should be identified and given credit to. Pay special attention to relevance and pertinence. This is the section where the client is told in detail what was done.

ANALYSIS & DISCUSSION

This is an important section because it is where those items determined or found in the process of investigation get examined and discussed. All that internal dialogue that takes place in the mind of the forensic engineer, for as long as it is relevant and pertinent, should become part of the narrative.

All possible theories should be taken into consideration and through a process of elimination arrive to the one best fitting the case.

This is where all the hints, evidence and facts fall into place in contrast with the questions asked by the client. Here is also where the engineer lays down all his theories and those opinions that he should be prepared to defend in court or in front of his peers at some future date.

Care should be taken, however, not to digress or wander into areas disconnected or which were not directly asked or were not requested to be investigated by the client.

CONCLUSION(S)

After an introductory sentence, such as this one:

Based on our observations, investigation and analysis, as well as to a fair and reasonable degree of engineering conviction, we conclude as follows:

Conclusions should follow immediately after and they should be listed in concise and precise short statements:

1.

2.

3.

Those conclusions should be directly consistent not only with the observations, investigation and analysis performed, but also with the questions posed by the client on his assignment sheet.

4.0 The Short Report

There are cases where a short report is applicable either as requested by the client, or as a way to allow the client to be fully aware of the contents, in such a manner that he can have the choice of letting the process continue its course or defend himself from the disadvantages of the *discovery process.*

A typical short report is not furnished with photographs, graphics, appendices or attachments. Generally three pages are good enough to accommodate its material according to the following table of contents:

1. Introduction & Background

2. Investigation & Analysis

3. Conclusions.

5.0 CASE HISTORY

From our files we have selected to accompany this Part IV a case of a partial collapse of a reinforced concrete parking building in the City of Gaithersburg, Maryland.

During the Winter months when salt was commonly used to retard ice formation on the street pavements, vehicles brought in the salt on their tires and fenders and as a result, saline water runoff would accumulate on the concrete slabs of the parking building and eventually would permeate through cracks already developed by either poor workmanship, concrete shrinkage, creep or temperature differentials, thus reaching the reinforcing steel which would corrode with its resulting volumetric increase, which expansion in turn, would not only deteriorate the steel but also create more cracks, thus debilitating the concrete structure even further in an endless vicious circle of endangerment.

In a nut shell, the above description fits well in the picture that sets the stage for the partial parking garage collapse you are about to read and digest as one of those cases the forensic engineer must be ready to face in his practice as answer seeker.

This case is going to be a challenge for you, as it certainly was a challenge for us in the quest for a fair answer which ultimately would have affected the livelihood and reputation of either, the general contractor, the demolition subcontractor, the engineer-of-record or perhaps that of the three of them as a case of shared responsibility.

Furthermore, because the variables were pointing in all different directions, this case also exhibited the characteristics and indicators of the typical case which would have to ultimately be decided by the court system. Consequently, it was prepared with the proper and careful preservation of evidence and the necessary documentation to be effectively defended and proven in a court of law.

Author's Note:
The names of participants in this case have been changed or modified so as to protect their identities.

PRINCESS ORCHARD PARKING GARAGE FAILURE

PREPARED BY

Ruben A. Gomez, P.E.
Forensic Engineering Corporation

Date of Loss: October 5, 1993
Date of Report: July 13, 1996

FEC File #5532

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 On October 8, 1993, the office of Forensic Engineering Corporation (FEC) was requested to examine the site of a car parking garage partial collapse. Such structure was part of a seven story office building located on the southwest of the Princess Orchard Plaza (please see Exhibit A) in the City of Gaithersburg, Maryland. In this opportunity FEC was asked to observe the collapse conditions and render a verbal report of its preliminary findings.

1.2 Subsequently on December 9, 1993, the client directed FEC to specifically analyze the slab collapse case and make a cause determination.

1.3 Finally on June 7, 1996, an authorized representative of the client requested by letter, the preparation of a "final report regarding the cause(s) of the loss".

2.0 BACKGROUND

2.1 According to the records available, the construction of the Princess Orchard Office Building was completed in the year 1973. The parking garage area had a documented history of concrete slab cracking, spallings, exposed reinforcement, water intrusion and salt deterioration. Those facts were well described in inspection reports prepared by Bridges Associates as part of their Condition Survey dated February 27, 1990, as well as a second Condition Survey dated August 7, 1992 prepared by Altman Associates.

2.2 In late August 1993 the building owner, Federal Investment Trust (FIT) entered into a contract for the parking garage listed concrete repairs with Prometheus Construction Company. Said repairs were to proceed according to the plans and specifications dated August 8, 1993 as prepared by Sullivan Consulting Engineers, P.C. In order to reduce noise, vibration and dust generation to a minimum, the plans called for a system of controlled concrete removal called *hydro-demolition.* As the name implies, demolition was to be performed by applying a water jet at an extremely high pressure and strong enough to slice through a piece of carbon steel.

2.3 After all demolition had been completed and the contractor had started the clean up, on October 5, 1993, shortly before 8:00 AM, the vibration generated by a motor caused a progressive collapse which once set in motion rapidly propagated to an area of approximately nine thousand square feet (9,000 SF) of concrete slab surface area.

3.0 FIELD OBSERVATIONS

3.1 On October 11, 1993, members of our office staff conducted a thorough investigation of the slab collapsed area. Previously to our coming to the site, access had been secured with the help, authorization and witnessing of the following executive members of the Prometheus Construction Company, Mr. James Brunel, Executive Vice-President; Mr. Jeremy Crawford, Project Manager and Mr. Michael Brunel, Prometheus' General Superintendent for the State of Maryland.

3.2 Enclosed Exhibit B shows a partial site plan of the subject building and its surrounding areas from where Pictures #1 was taken.

3.3 On our way to the parking garage we observed vertical cracks on both front corners of the building.

3.4 Later on we found out that all four corners of the building showed deep cracks through the brick veneers indicating undue and unanticipated movement at those locations.

3.5 Once at the second basement where most of our observations were going to concentrate, a large amount of debris was still scattered through the lower basement floor. Large portions of concrete were still hanging from reinforcing bars projecting out of the still standing floor slab. Cleaning crews were busy cutting concrete debris into smaller pieces to make removal less cumbersome and easier for removal by forklifts and loaders which were loading the rubble on waiting trucks outside. According to the General Superintendent present at the site, no deaths or injuries had been reported and all assigned workmen had been accounted for.

3.6 According to the repair plans as prepared by Sullivan Consulting Engineers, P.C., the engineer-of-record, the maximum cut was to be limited to a 3 in. penetration (either top or bottom) into the existing concrete slab. Instead, our field measured cuts ranged from three (3) to five (5) inches, well in excess of the prescribed depths. Present members of the staff assured us that such cuts were previously approved by the engineer-of-record, fact that he denied when questioned on a later date interview. Three "column strips" had been cut to a depth well over three inches according to our field observations.

3.7 The extent of the collapsed slab area were described in both, elevation and plan views, as they appear depicted herein on enclosed Exhibits C and D.

3.8 Statements made by the project manager (Mr. Crawford) indicated that the very moment when the loader's operator started the engine, the resulting vibration put the event in motion. The collapse mechanism developed slowly, thus allowing the loader's operator to escape unharmed and away from the danger area. Progressive collapse extended in all directions and when through involved a total of 21 contiguous bays before equilibrium was restored at an expansion joint on the North side at column grid line 7, and on the West all the way to the edge of the slab. Stiffer column strips on the South and East ends resisted the course of propagation. Original location of the loader prior to collapse was given as adjacent to column P-4 and within the limits of bay P-Q-4-5. We found such location to be consistent with the view of the loader caught under the debris, as well as other pieces of evidence collected at the site.

3.9 Our examination of the collapsed area, as shown on Exhibit D, was as thorough as the prevailing conditions allowed at the time. Of all conditions observed, two were of particular interest to us: a) a sheared off portion of the slab adjacent to the stairway and between columns M-4 and N-4, the exposed concrete coarse aggregate showed all the characteristics of being of the lightweight type. That was the first news for us, for nobody ever mentioned it before in all our inquiries. The second condition had to do with the fact that on the same column strip, concrete had been removed by the demolition subcontractor from both top and bottom layers, thus reducing the overall slab concrete thickness from 10½ down to an un-reinforced concrete core of just 5½ inches and technically unable to carry its own weight. Even worse, there was no evidence of even an attempt to shore the area to avoid what became the unavoidable result of such negligent act.

3.10 Exhibits E and F were prepared to compare the proverbial *as designed vs. the as built* conditions. The comparison between the two came to show a loss of 1¼ in. in *effective depth,* not only having exceeded construction tolerances, but with the resulting loss in slab flexural capacity of some 20% in the best of scenarios.

3.11 At first look, shoring seemed to be light and sparse enough to be of serious concern, some of the few visible shoring posts had buckled (see Picture #3) under the severe overload. As we walked deeper into the rubble, shoring became non-existent at the most critical areas. Approved shoring plans were unavailable at the contractor's site office, therefore, we requested from the contractor to furnish us with a set of those plans.

3.12 Shoring plans were finally and reluctantly submitted to us by late November 1993. On the first page there was a conspicuous Note #2 reading: "Maximum depth of concrete removal is assumed to be 3 inches. Should the contractor encounter a need to exceed those allowed 3 inches, full depth shoring plan shall apply". Although such plans did not specify the meaning and extent of the suggested "full depth shoring", it was at least implied that a more complete shoring arrangement should have been implemented in such an event. However, such requirement seemed to have been either ignored or overlooked by the contractor's field superintendent.

4.0 ANALYSIS & DISCUSSION

4.1 For our analysis, shoring lay-out and distribution pattern were taken from the shoring plans dated July 19, 1993 as prepared and submitted by the project's general contractor, Prometheus Construction Company. A stress analysis of the collapsed area was prepared accordingly.

4.2 Typical bays were selected in the vicinity of the loader location (see Exhibit G). Static and dynamic loading models were used in the determination of critical stresses. A uniformly distributed static load of 94 PSF was applied with the magnifying effects of acceleration induced by the loader engine's cyclical vibrations. The following conditions and results were ultimately identified:

4.2.1 Under static loadings, non reinforced concrete sections exceeded their ultimate tensile strength in both positive and negative moment zones.

4.2.2 Under dynamic loadings, shear failure likely started at columns P-5 and P-6 progressively propagating in all directions.

4.2.3 Shoring specified capacity was exceeded under both static and dynamic loading models.

4.3 We must make emphasis on the fact that although the American Concrete Institute (ACI) recommends that "tensile strength of concrete shall be neglected in flexural calculations of reinforced concrete". Inasmuch as that constitutes a normal and sound practice in general design work, in this case it would have been unrealistic to presume a zero tensile strength. Consequently, we should allow what documented testing suggests:

$$f_t = 1.6\sqrt{f_c'}$$

4.4 Tests performed by Bridges Associates in February 1990 using concrete cores taken from the now failed slab, suggested an average ultimate compression strength of 3,345 PSI. Later on in August 1992, Altman Associates tested sample cores with the resulting average compression strength of 3,410 PSI, value which we used below in the prediction of the ultimate tensile strength:

$$f_t = 1.6 \sqrt{3410} = 1.6 \times 58.40 = 93 \text{ PSI}$$

On the other hand, our calculations indicated that the tensile strength in sections marked as C on the enclosed Exhibit G, should have reached a value of 273 PSI under static loading, which was three (3) times higher than the predicted ultimate tensile stress.

4.5 It is interesting to notice despite the fact that ultimate tensile stresses were greatly exceeded, failure did not occur under static loads, for two-way slabs have the ability to redistribute stresses for an extended period of time.

4.6 It should be noticed however, that:

4.6.1 By exposing large areas of negative (top) bars, the flat plate lost all its capacity to handle stress reversals. Additionally,

4.6.2 By placing shores in less than desirable locations, the basic function of the flat plate was altered, such as it took place at bays P-Q-2-3; P-Q-3-4; P-Q-5-6; P-Q-6-7; L-M-5-6; L-M-6-7; M-N-4-5; and M-N-5-6.

4.7 As for the demolition shoring plans described on Paragraph 3.12, after giving all considerations and benefits, we found them to be borderline adequate for the intended purposes and assumed conditions. However, as those presumed limits were exceeded the shoring system should have been upgraded from mere point load jacks to spreaders, as conceptually shown on Exhibit H. Furthermore, those areas where full specified penetration was exceeded or the concrete slab had been stripped off from both top and bottom critical zones, if anything, common sense should have dictated the use of continuous false work, as described in standards such as the ACI SP-4 titled “Formwork for Concrete”.

4.8 In order to have a complete picture of the problem at hand, we carefully examined the contracts between the building owner, Federal Investment Trust (FIT) and Prometheus Construction Company, as well as the contract between FIT and Sullivan Consulting Engineers, P.C. After going through all the normal language concerning performance and liabilities, we concluded that the actual responsibilities of Sullivan was to prepare a repair program (plans and specifications) and provide the necessary field supervision to ascertain that those plans and specifications were brought to proper completion. On the other hand, Prometheus’ responsibilities consisted in the implementation of those same plans and specifications to a safe and adequate completion.

5.0 CONCLUSIONS

5.1 Based on our observations, investigation and analysis, as well as on a reasonable degree of engineering conviction, FEC concludes as follows:

5.1.1 The slab collapse was one of progressive pattern and was initiated by one or more of these modes: shear/bending/shoring. Concrete slab failure likely started within or the vicinity of bay P-Q-5-6 and propagated in all directions. As shores buckled under the added compression, the failure mechanism followed the proverbial pattern of the “domino effect”.

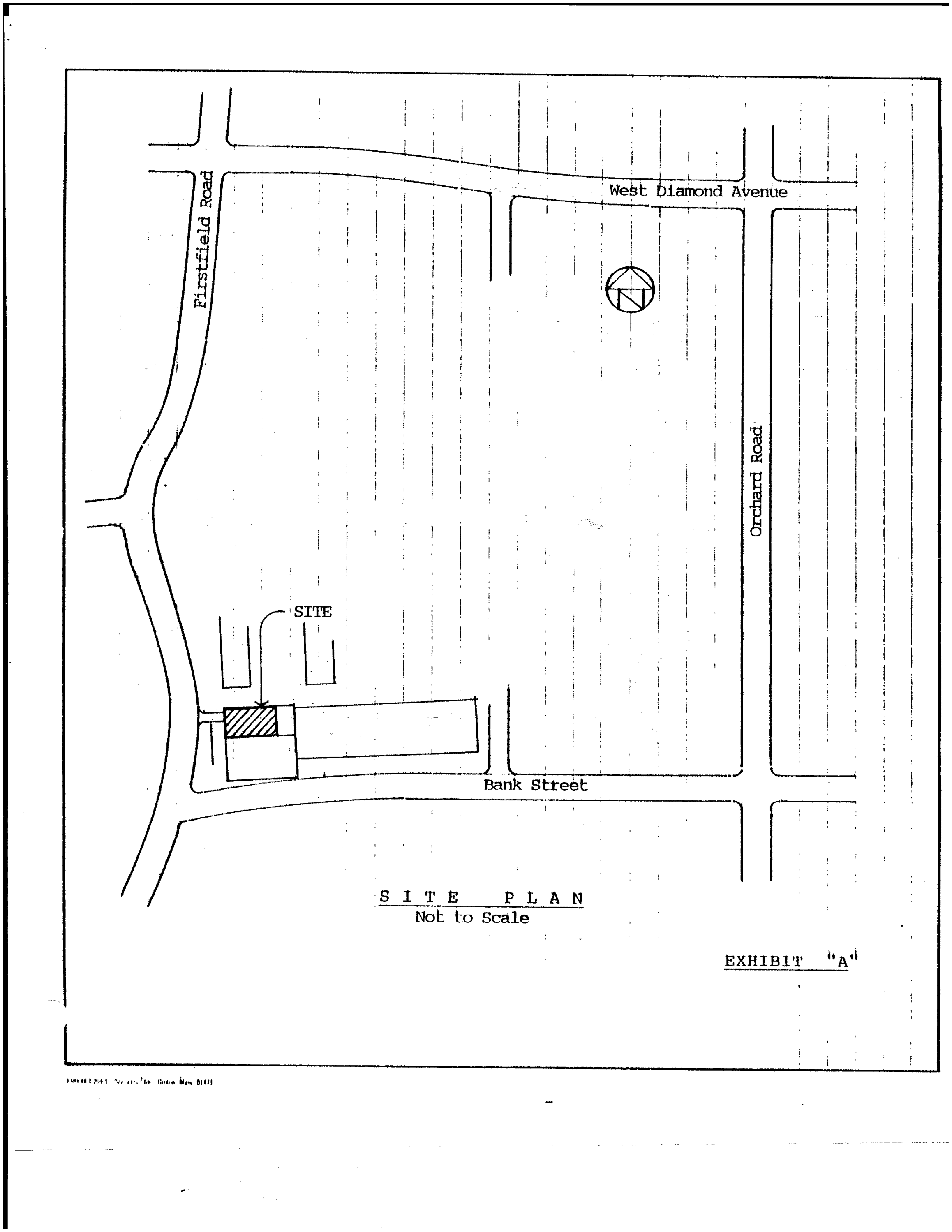
5.1.2 Failure was caused by a combination of excessive concrete cutting and inadequate shoring, in that order.

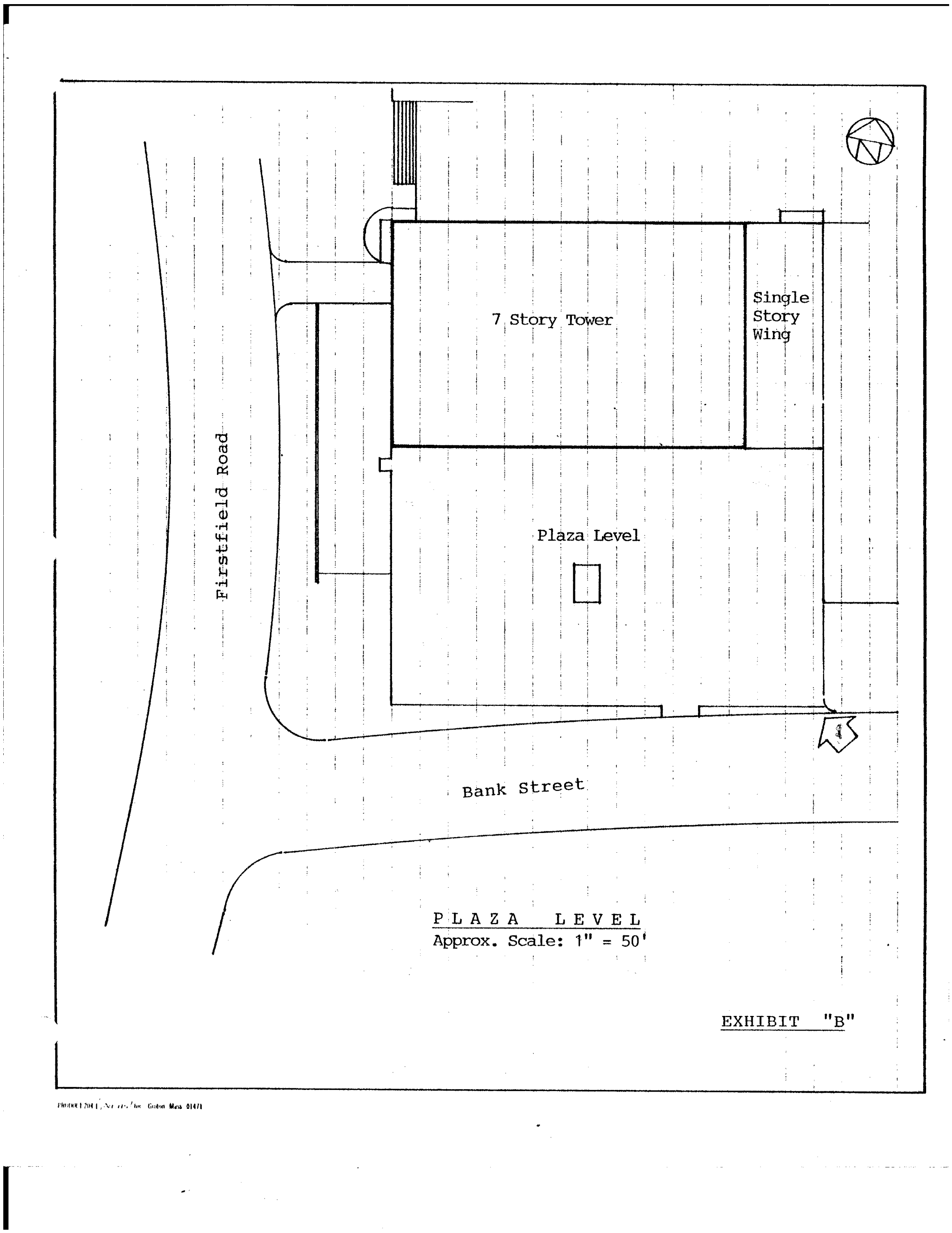
Respectfully submitted,

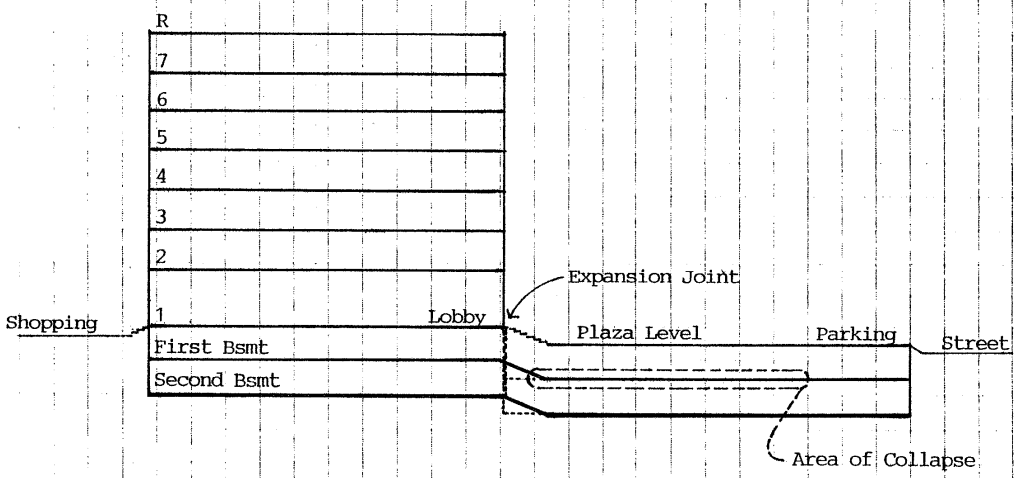
(Signed and dated: 07/13/1996)
Ruben A. Gomez, P.E.

APPENDIX I

Exhibits A through H


West Diamond Avenue
Firstfield Road
Orchard Road
SITE
Bank Street
N
S I T E P L A N
Not to Scale
EXHIBIT "A"


7 Story Tower
Single Story Wing
Firstfield Road
Plaza Level
Bank Street
N
PLAZA LEVEL
Approx. Scale: 1" = 50'
EXHIBIT "B"



SCHEMATIC CROSS SECTION
Approx. Scale: 1" = 40'

EXHIBIT "C"

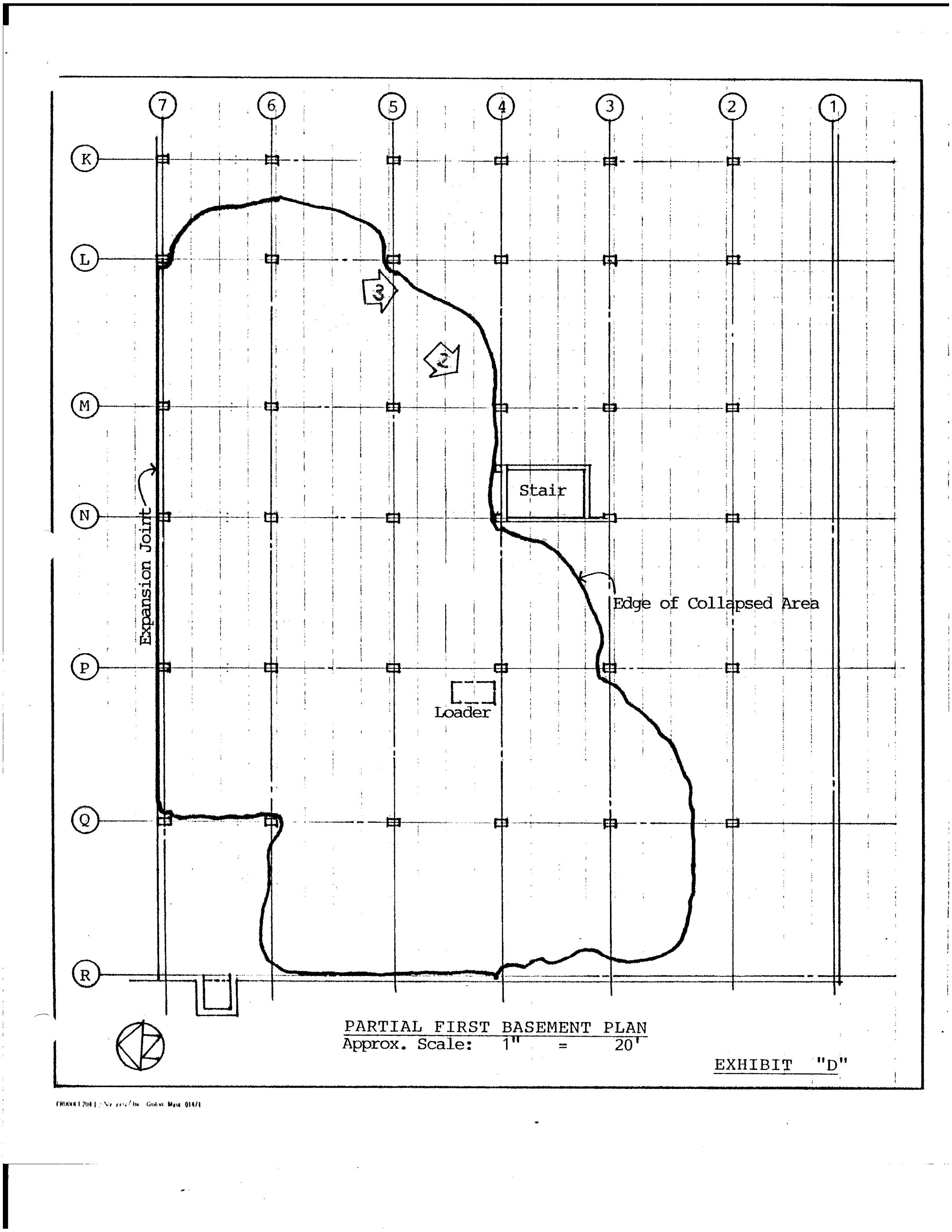
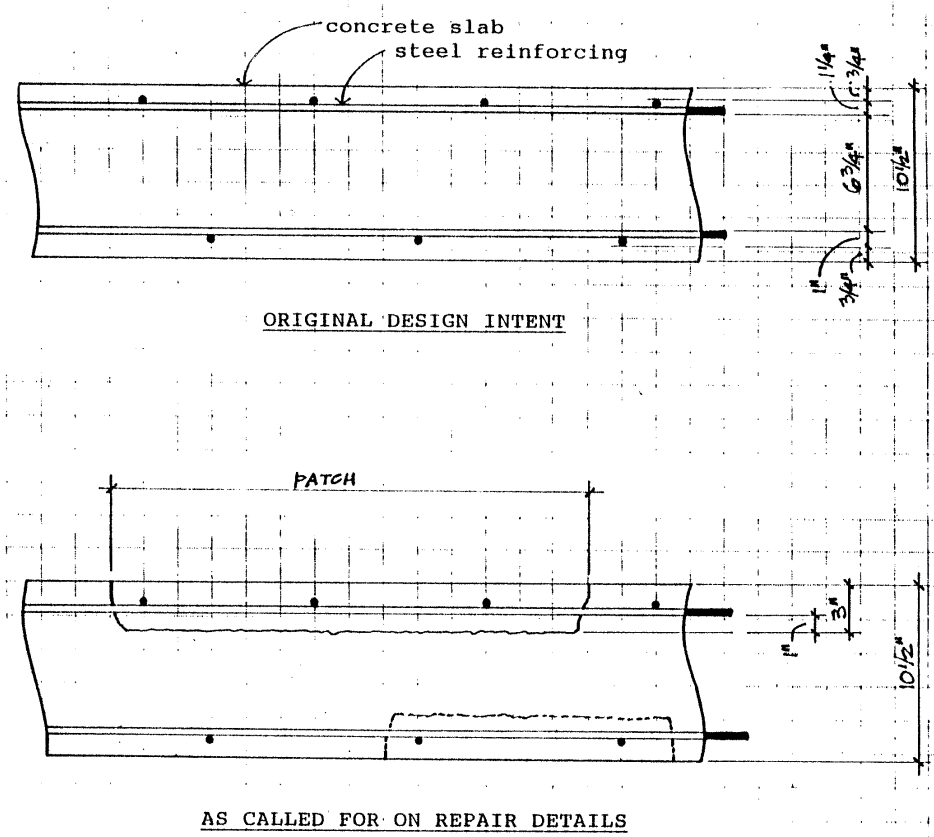

7
6
5
4
3
2
1
K
L
M
N
P
Q
R
Stair
Expansion Joint
Edge of Collapsed Area
Loader
PARTIAL FIRST BASEMENT PLAN
Approx. Scale: 1" = 20'
EXHIBIT "D"

EXHIBIT "E"

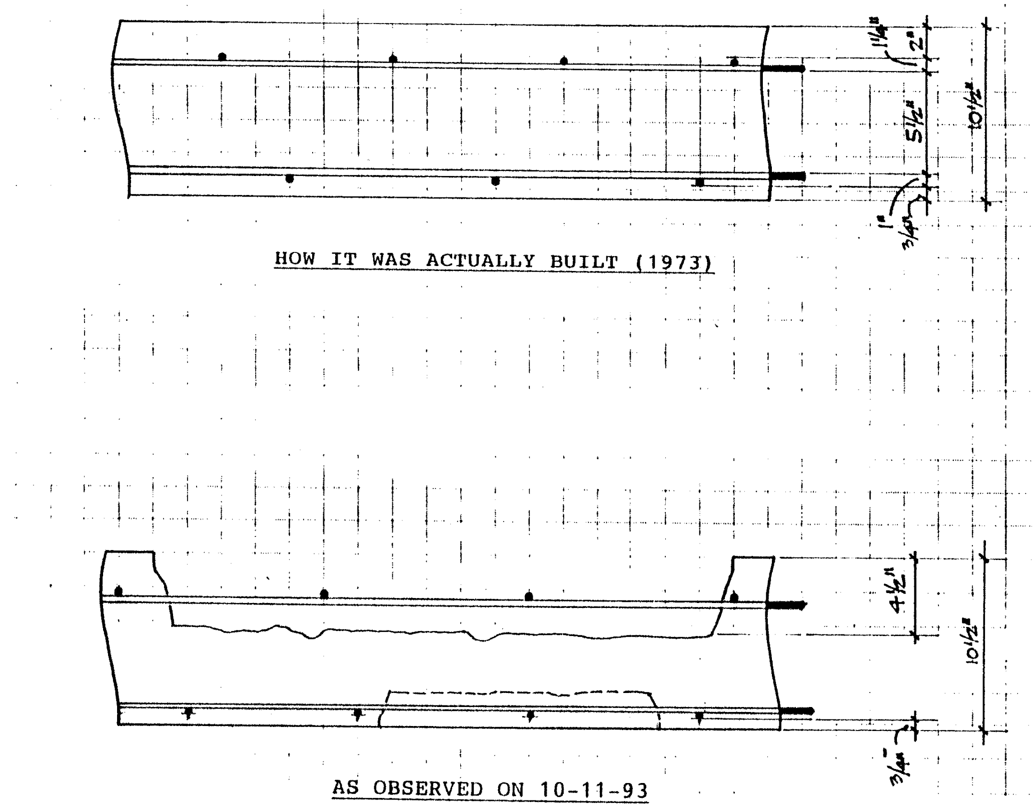


TYPICAL FLAT SLAB DETAILS

SCALE : 1½" = 1' - 0"

12/16/93

EXHIBIT "F"



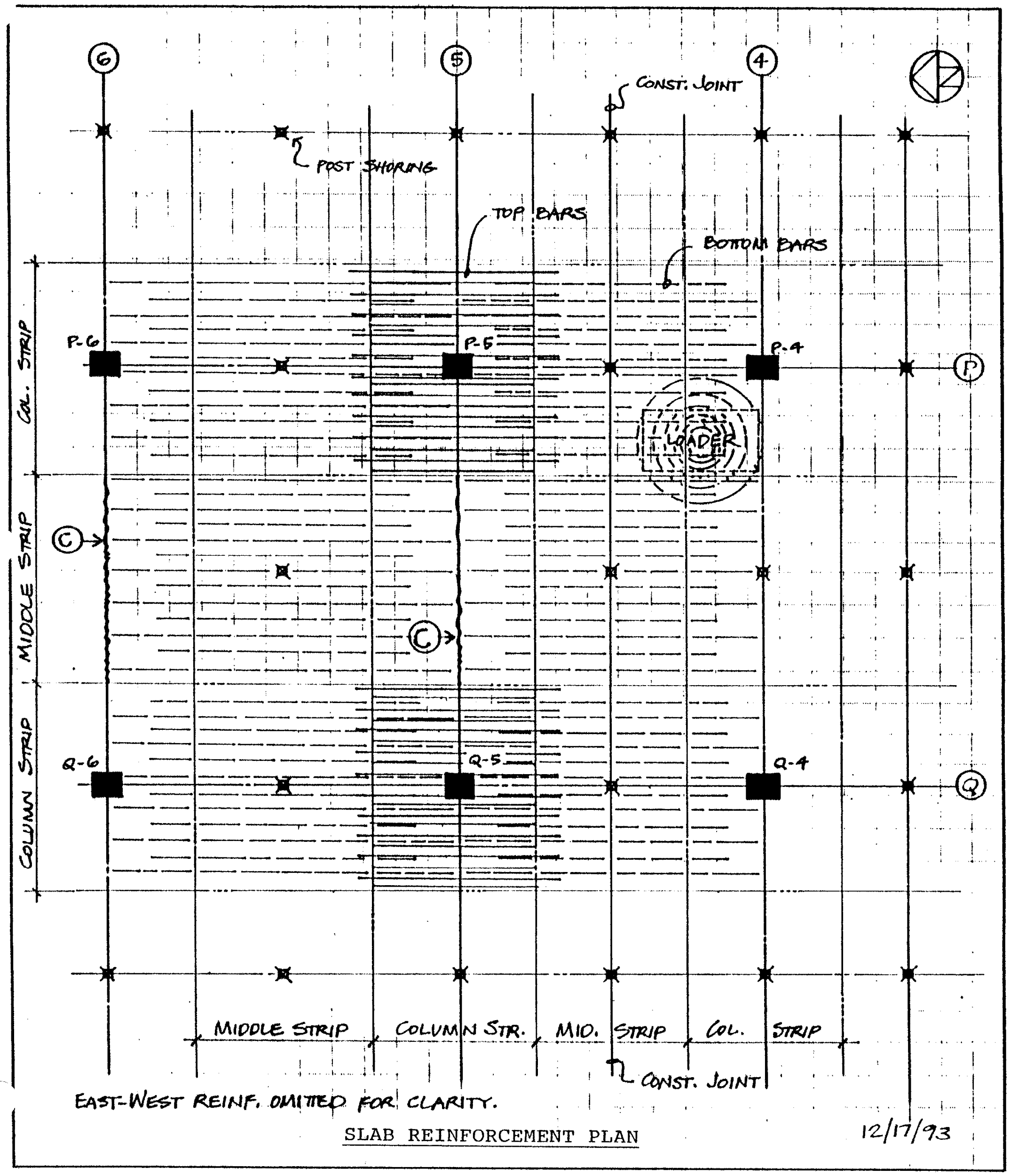
AS-BUILT CONDITIONS

SCALE : 1½" = 1' - 0"

12/16/93

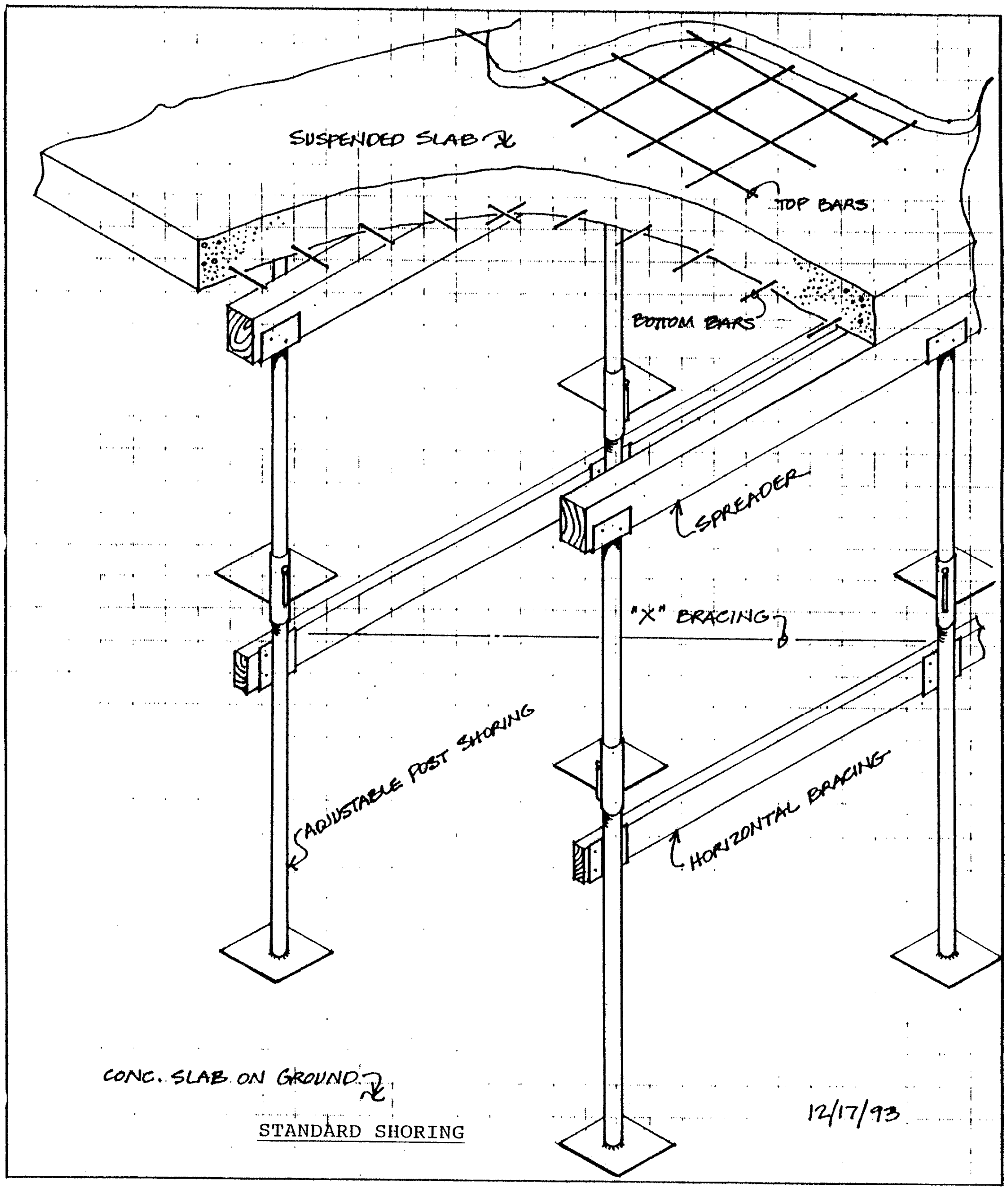
Scale: 1/8 in. = 1 ft.

EXHIBIT "G"



SLAB REINFORCEMENT PLAN

EXHIBIT "H"



STANDARD SHORING

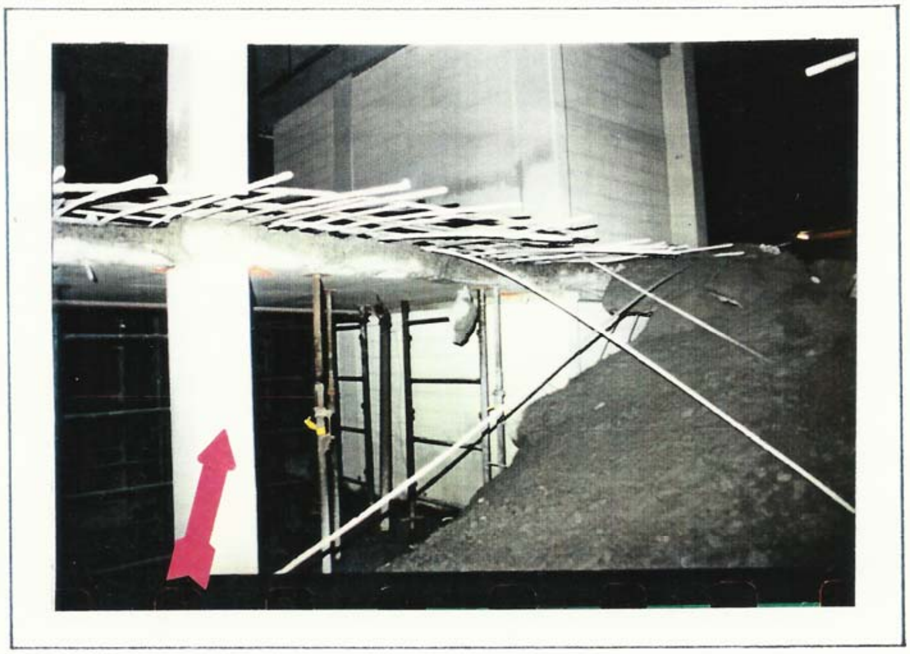
APPENDIX II

Pictures #1 through #3

PICTURE #1

Date Taken: 10/11/1993

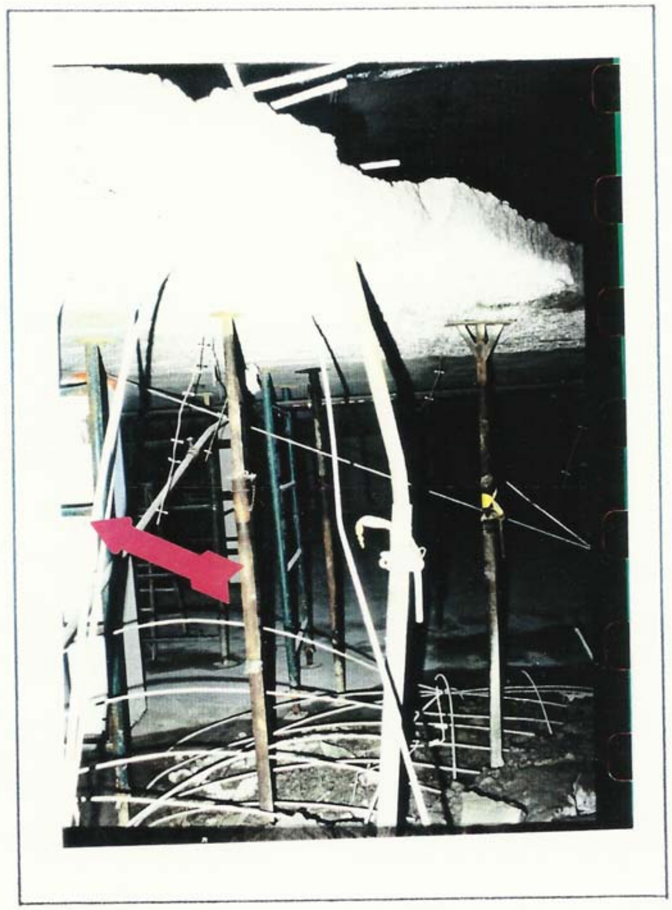
Office tower and plaza level as seen from Bank Street.



PICTURE #2

Date Taken: 10/11/1993

View of sheared concrete slab adjacent to stairway.
Arrow points at column marked M-4.



PICTURE #3

Date Taken: 10/11/1993

Area of failed slab which had been stripped off both top cover and bottom soffit.
Arrow points at column marked L-4.
Shoring on foreground had buckled under concrete weight.

6.0 POST REPORT REVIEW ON RESPONSIBILITY

Judging by the degree and amount of arguments on both sides, it was obvious to anyone involved that the just described case was inexorably on its way to court. At that point it would become a legal matter and would be for the judge to decide. However, there were some aspects of it that remained as grounds for speculation.

Before entering into the matter of responsibility, there was one lingering point that circulated amongst the members of our analysis team. What really happened to the shoring plans? Why were they not at the construction office and available for inspection? Is it possible that when requested they were nonexistent and then prepared in a rush within the time from the date of request and the date of submission? Or, did they exist but were "inconvenient" and consequently modified during the same period of time? If so, was there that much of a gain to warrant such a sneaky manipulation?

When it came to the matter of responsibility, the general contractor and his demolition sub-contractor were responsible of completing the work in a substantial and safe way to give the owner a quality product. On the other hand, the engineer-of-record was responsible not only to produce an adequate set of plans and technical specifications, but was also responsible to supervise the work and make sure that it was done accordingly. Part of that responsibility was also to assure that the work was performed in a safe manner and with the appropriate shoring system. Then, why did he allow the contractor to prepare his own shoring plans? And once he did that, why did he not make sure that the proper shoring was installed according to those plans?
You may play the judge and decide.

7.0 CLOSING STATEMENT

There is another important item on the above described case and report regarding chronology that needs some explaining and here it is:

Date of Loss (DOL):	October 5, 1993
Date of Collapse Examination (by FEC):	October 11, 1993

At the request of our client the case was placed on hold until certain negotiations took place. No settlement was reached.

Date of Request of Cause Determination:	December 9, 1993

Another long attempt to settle. Legal manipulations followed. However, all attempts on either side were futile.

Date of Request for Final Report:	June 7, 1996
Date of Report Submission by FEC:	July 13, 1996

What would normally take three to four weeks to process, from site examination to report completion and delivery, in this particular case took almost three years to see it through.

These series of delays although not common, however, could not be ruled out as an improbable dilatory strategy which may or may not have worked, for as long as the time invested in such maneuverings would not have exceeded the case's *statute of limitation.*

Now in closing, after studying Parts I, II and III of this course, as well as subsequently completing this Part IV, any engineer inclined to practice forensic engineering would *almost* be on his way to an exciting new career. The final Part V of this series will be available in the near future. Meanwhile, happy trails!

END