# Monitoring Building Tilt, Bridge Dynamic Deflections, and Floor Vibrations during Construction Activities for Structural Performance and Client Satisfaction

## Structural Health Monitoring


Prasad Samarajiva, Ph.D., P.E.

Narendra Gosain, Ph.D., P.E.

Dilip Choudhuri, P.E.

Structural Diagnostics Services
Walter P Moore


March 16, 2011

# The Absolutes of Life

# Some Other Absolutes of Life (other than Death and Taxes)

- The Gosain Dictum No. 1
  - "So long as structures will keep on getting built, failures will keep on occurring."

# Some Other Absolutes of Life (other than Death and Taxes)

- The Gosain Dictum No. 2
  - “Failures will keep Forensics Engineers busy for a long time”

# Some Other Absolutes of Life (other than Death and Taxes)

- Primary Causes of Engineering Failures
  - Deferred maintenance
  - Design flaws
  - Material failures
  - Overloading
  - Combination of all the above

# Some Other Absolutes of Life (other than Death and Taxes)

- Gosain and Prasad Observation No. 1
  - Fear of failure will spur some owners to action!

# Some Other Absolutes of Life (other than Death and Taxes)

- Gosain and Prasad Observation No. 2
  - An action may be Structural Health Monitoring!

# Nature of Failures

- Some failures are sudden and catastrophic, and some failures just take their time…

# How Can We Reduce Engineering Failures?

- Structural Health Monitoring (SHM) can be very helpful in serving as an alarm system for preventing both types of failures ………….
- But what is Structural Health Monitoring?

# What is Structural Health Monitoring (SHM)?

- Definition: The <u>process of implementing a distress or damage detection strategy</u> for aerospace, mechanical and civil engineering structures is referred to as Structural Health Monitoring or SHM.
- Not a new concept
  - Has been around for several decades
  - Advances in electronics made it easier to implement.
- Several non-destructive evaluation (NDE) tools available for monitoring.

# How old is SHM?

- SHM work goes back almost 80 years.
- Limited to major structures
  - Dams
  - Bridges
  - Some early high rises
  - Unique structures
- Significant interest in the past 10 years.
  - Life-safety issues
  - Economic benefits
  - Performance evaluation
  - Affordable

# Case History from the Past …

# San Jacinto Monument Mat Foundation SHM

## 1981 Study

1. Monument suspected to have tilt: Measured tilt to be within construction tolerances
2. Excessive settlement suspected: Monument supported by a monolithic mat foundation. Top of mat built exposed.
3. Discovered that a settlement monitoring program was set up during construction in 1936
4. Searched archives for data: Found documents in the archives of the Houston Public Library
5. A Geotechnical engineer was retained to review past data

San Jacinto Monument
Built 1936
La Porte, Texas

# San Jacinto Monument Mat Foundation SHM

MEM. AM. SOC. CIV. ENG.

ROBERT J. CUMMINS
CONSULTING ENGINEER
HOUSTON, TEXAS

BANKERS MORTGAGE BUILDING

May 1, 1936

San Jacinto Memorial Tey 1975-1

Mr. A. C. Finn, Architect,
Bankers Mortgage Building,
Houston, Texas.

Dear Sir:

In compliance with your request we take pleasure in stating that the San Jacinto Memorial has been designed to withstand a wind velocity of 125 miles per hour, which according to the best authorities produces a pressure of 50 pounds per square foot on a flat surface, normal to the direction of the wind.

Our calculations show that the soil pressure with no wind on the shaft will be 4700 pounds per square foot. With the wind blowing parallel to two sides of the shaft the maximum pressure on the soil will be 5700 pounds per square foot, and with the wind blowing in the direction of a diagonal the maximum soil pressure will be 6300 pounds per square foot.

According to the tests conducted by the Research Department of the University of Texas, the soil on which this monument will rest will safely sustain these loads, and the settlement over a period of years will not be excessive, amounting - according to the report submitted by the University - to eventually $5\frac{1}{2}$" in 250 years, or 5" in 100 years, or about $2\frac{1}{2}$" in 5 years.

Yours very truly,

Robert J. Cummins

CONSULTING ENGINEER.

RJC:AL

From City of Houston Public Library Archives

# San Jacinto Monument Mat Foundation SHM

According to the tests conducted by the Research Department of the University of Texas, the soil on which this monument will rest will safely sustain these loads, and the settlement over a period of years will not be excessive, amounting - according to the report submitted by the University - to eventually $5\frac{1}{2}$" in 250 years, or 5" in 100 years, or about $2\frac{1}{2}$"in 5 years.

Yours very truly,

CONSULTING ENGINEER.

From City of Houston Public Library Archives

# San Jacinto Monument Mat Foundation SHM

( C O P Y )

FEDERAL EMERGENCY ADMINISTRATION OF PUBLIC WORKS

State Director

Fort Worth, Texas
May 28, 1936

Docket No. TEX-1975 R
Houston
San Jacinto Memorial

Mr. R. J. Cummins,
Bankers Mortgage Bldg.,
Houston, Texas.

Dear Mr. Cummins:

Since one of the major problems in connection with the San Jacinto Memorial Tower concerns the safety and adequacy of the foundation, it occurs to us that, as a means of checking the completed structure with design assumptions, and of keeping informed as to actual subsoil conditions, it might be advisable to install pressure cells at such points under the tower as you might determine. Especially during the period of construction and the first months of existence of the completed shaft it is essential that careful watch be maintained over foundation behavior.

If you will carefully consider this phase of the project and then feel inclined to submit a change order to add an installation of soil pressure cells and permanent bench marks for the purpose of checking foundation conditions we shall be glad to carefully consider such items of additional cost as you may propose.

Sincerely yours,

JULIAN MONTGOMERY
State Director

Sgd. By: Uel Stephens
UEL STEPHENS
Chief Engineer, FWA (Texas)

For the Administrator

FWC:H

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# San Jacinto Monument Mat Foundation SHM

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From City of Houston Public Library Archives

# San Jacinto Monument Mat Foundation SHM

CE—005

(*Reprinted from* CIVIL ENGINEERING *for September 1938*)

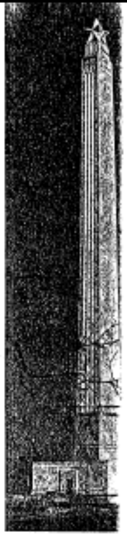
## Settlement Studies on San Jacinto Monument

*Field Observations Supply Data on Behavior of Isolated Footing on Deep Bed of Clay*

FROM A PAPER PRESENTED BEFORE THE TEXAS SECTION

*By* RAYMOND F. DAWSON

MEMBER AMERICAN SOCIETY OF CIVIL ENGINEERS
TESTING ENGINEER, BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS, AUSTIN, TEX.



Courtesy of W. B. Ba[illegible]

*A FIELD research project that should go far towards confirming or challenging the accuracy of settlement predictions has been in progress for almost two years at the San Jacinto Monument, in Texas. The monument rests on a 220-ft layer of clay, and the footing is a monolithic slab 124 ft on a side. At time intervals determined by the rate of settlement, the elevations of 44 points on this slab are carefully determined, and the settlements are compared with those previously predicted from laboratory tests and theoretical considerations. The accompanying article describes the technique of making the observations and presents the outstanding results to date.*

AN ideal opportunity to observe the action of an isolated footing on a deep bed of clay is afforded by the San Jacinto Monument, near Houston, Tex. The studies, which are being carried on by the Bureau of Engineering Research of the University of Texas, include both laboratory tests and a continuing series of settlement observations on the structure itself, and have already provided valuable data on the coordination of laboratory and field results.

Design and construction of the San Jacinto Monument were covered in an article by Robert J. Cummins, M. Am. Soc. C.E., in the July 1937 issue of CIVIL ENGINEERING. As he explains, the foundation is a monolithic concrete base 124 ft square, reinforced with 2-in. square bars spaced $6^1/_2$ in. on centers in each direction. This footing rests on red clay 15 ft below the natural ground level, and the unit dead load on the underlying soil is 2.35 tons per sq ft. Borings show that the clay continues to a depth of 100 ft, and logs of wells drilled in the vicinity indicate that it extends to a depth of 220 ft and is underlain by a bed of sand. Physical characteristics of the clay are given in Table I.

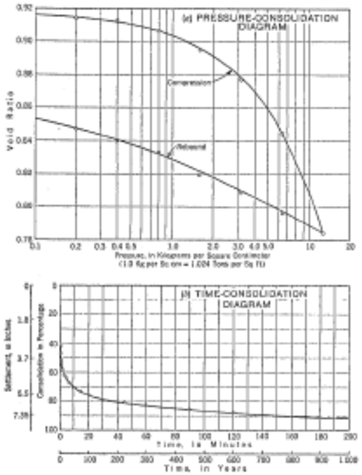



FIG. 1. DATA FROM LABORATORY TESTS

Prior to the construction of the monument, samples of undisturbed soil were obtained from the foundation area, coated with paraffin to prevent loss of moisture, and taken to the Bureau of Engineering Research for consolidation tests. (The general method of performing such tests was described by Spencer J. Buchanan, Assoc. M. Am. Soc. C.E., in the August 1937 issue.) Results from a typical specimen are presented in Fig. 1.

A load applied to the surface of the ground distributes itself throughout the soil in diminishing intensity in both the vertical and the horizontal direction away from the axis of the loading. Therefore, in order to estimate the probable settlement under a loaded area, it is necessary to determine the pressure distribution at a number of points under the area. Vertical pressures were computed at various depths for points under the foundation by a method given in Circular No. 24 of the University of Illinois Engineering Experiment Station. This is an integration for the Boussinesq equation, which assumes a homogeneous elastic solid of indefinite extent. As soils in general are not homogeneous, isotropic, or perfectly elastic, accurate results cannot be expected. Typical pressure profiles at five points under the footing are given in Fig. 2. These points were so chosen that the average of the pressures beneath them at any given elevation should be approximately the average of the pressure beneath the entire footing at that elevation.

TABLE I. ANALYSIS OF CLAY SOIL FROM MONUMENT SITE

| | |
|---|---|
| Initial moisture content (by weight) | 30.75 per cent |
| Initial degree of saturation | 94.35 per cent |
| Initial void ratio | 0.9138 |
| Liquid limit | 75.20 |
| Plastic limit | 28.43 |
| Plasticity index | 46.77 |
| Centrifuge moisture equivalent (waterlogged) | 35.18 |
| Shrinkage limit | 6.95 |
| Volume shrinkage (based on wet volume) | 68.0 per cent |
| Volume shrinkage (based on dry volume) | 136.1 per cent |
| Linear shrinkage | 25 per cent |
| Shrinkage ratio | 2.037 |
| Absolute specific gravity | 2.795 |

From City of Houston Public Library Archives

# San Jacinto Monument Mat Foundation SHM



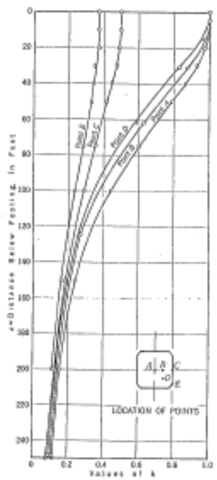



FIG. 2. STRESS DISTRIBUTION UNDER FOUNDATION

Values of $k$ for Use in $p_z = kp$, Where $p_z$ Is the Vertical Pressure at Depth $z$, and $p$ Is the Unit Load on the Soil

The soil was then divided into imaginary layers 1 ft thick in the first 100 ft of depth, and 25 ft thick in the lower 100 ft. For each of these layers the average pressure due to the applied load was determined, as well as the average load due to the weight of the soil above the layer. The average weight of the soil above gives the initial pressure on the layer, and by adding to this the pressure caused by the applied load we obtain the average final pressure.

In excavating for the foundation, 15 ft of clay was removed. Theoretically, the addition of a weight equal to that of the soil removed will cause no settlement. Actually there will be a slight rebound when the soil is removed, and an equal amount of settlement when the equivalent load is applied. In this case the soil weighed 120 lb per cu ft, and a layer 15 ft deep weighed 0.9 ton, giving an effective load of 1.45 tons per sq ft on the soil instead of the calculated load of 2.35 tons per sq ft.

Taking the first layer of 10 ft under the footing, we find that the average initial pressure due to the weight of the soil is $\left(15 + \frac{10}{2}\right)\frac{120}{2,000}$ or 1.2 tons per sq ft. The average added pressure due to a load of 1.45 tons per sq ft, reduced according to the pressure distribution curves, is 1.13 tons per sq ft. This gives a final pressure of 2.33 tons per sq ft. From Fig. 1($a$) we find that these pressures give an initial void-ratio of 0.901 and a final void-ratio of 0.887. Then we can calculate the settlement in this layer by $q = (e_i - e_f)h/(1 + e_i)$ where $q$ is the settlement of the layer; $e_i$, the initial void ratio; $e_f$, the final void ratio; and $h$, the height of the layer. For the given conditions, $q = 0.88$ in.

In a similar manner the settlement of each of the other layers was calculated, and also the total settlement equal to the summation of the settlement of all the layers, expressed as follows: $Q = \Sigma q = 7.35$ in.

According to the theory of the consolidation process, the rates of compression of two layers of the same material under the same pressure conditions are directly proportional to the squares of the "reduced thicknesses" of the layers. The reduced thickness of a soil is the thickness of the solids with all voids removed. It is the true thickness divided by 1 plus the void ratio.

By determining the reduced thicknesses of the various layers and adding them, we can obtain the reduced thickness of the whole clay stratum. From this we calculate that one minute on the sample is equivalent to five years on the structure if the conditions are the same in both cases. On the sample in the consolidometer there were porous stones both top and bottom, permitting water drainage in both directions. If the clay under the structure can drain in only one direction it will take 4 times as long to consolidate, since the rates vary as the squares of the thicknesses. On the San Jacinto Monument there is an impermeable concrete mat above the clay, and therefore it might be considered that the water could only escape to the sand below. On the other hand, all the voids of the soil are not filled with water, so that a lateral movement of the water is also permitted. Under these conditions we may expect the settlement of the structure to follow the sample, especially at early ages when the water can move laterally.

It has been found that 90 per cent consolidation on the sample is equivalent to 100 per cent settlement in the field. This is true because the last 10 per cent of the consolidation takes place very slowly (theoretically at infinity) so that a practical limit is set for the time of ultimate consolidation.

From Fig. 1($b$) we find that 90 per cent consolidation on the sample occurs in 160 minutes, which is 800 years on the structure. It may well be asked if 800 years is a practical limit, but by using this figure as a basis we can calculate the amount of settlement for shorter periods by placing scales on Fig. 1($b$) for time in years and settlement in inches. We then find the following predicted settlement:

| Time in Years | Per Cent Settlement | Inches Settlement |
|---|---|---|
| 800 | 100 | 7.35 |
| 100 | 75 | 5.51 |
| 5 | 50 | 3.68 |
| 1 | 35 | 2.57 |

The first requirement for settlement studies on a structure is permanent bench marks. The type selected for the monument observations is shown in Fig. 3. The essential parts consist of a 2-in. galvanized pipe 22 ft long used to case off the inner pipe from the soil. This depth is believed to be sufficient since the ground elevation is only about 18 ft above sea level. The outer pipe fits snugly in a hole bored in the ground and is approximately 4 ft shorter than the smaller pipe. The additional length of the inner pipe was driven into the ground. A

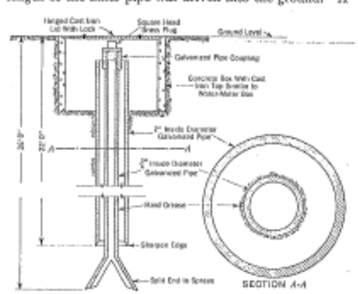



FIG. 3. PERMANENT BENCH MARKS

From City of Houston Public Library Archives

# San Jacinto Monument Mat Foundation SHM



brass plug in the top of the inner pipe is used as the bench mark. The top of the pipe is inclosed in a concrete box covered with a cast-iron lid.

Three bench marks were placed in different locations at least 275 ft from the outer wall of the monument. Every time settlement readings are taken, the elevations of these bench marks are checked and rechecked, and to date there has been no movement.

At the time the footing was poured, small cans filled with paper were placed in the surface of the concrete. Later the paper was removed and the cans were filled with mortar. Round-headed bolts were set in the mortar to serve as observation points. There were also a number of pipes going through the concrete footing which were used to support the mixer boom during the pouring. Steel rods were set in mortar at the bottom of these pipes in order that we might have some observation points at the bottom of the slab. The plan of the base, Fig. 4, shows the location of the observation points. In all, 50 were set, but 6 were destroyed during construction.

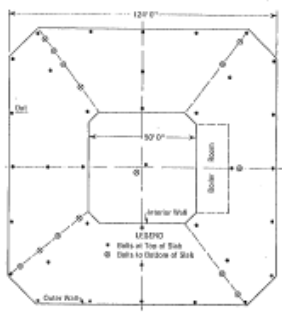



Fig. 4. Location of Observation Points

Construction forms and equipment prevented the taking of initial settlement readings until almost two weeks after the base was poured. Settlement during this period was approximately equal to the rebound caused by the removal of the soil.

The settlement observations are made by precise levels reading the target to 0.001 ft. A line from the three bench marks, using double turning points, is run into the basement and the elevations of the observation points are taken. The line is then carried back to the bench marks for a final check.

## Results of Observations to Date

Figure 5(*a*) shows the maximum, minimum, and average settlements as well as the unit load on the soil. Usually the first question asked is how the actual settlement compares with that predicted. It will be recalled that from the laboratory tests we predicted a settlement of 2.57 in. in one year, and this curve gives an average actual settlement of 1.9 in. in the first year. But the load on the laboratory sample was applied instantaneously while that on the soil was being applied gradually over a period of approximately one year. If it is assumed that all the load on the structure was applied at the halfway point of the construction period, the first year of settlement would be completed about May 1, 1938. On this date the average settlement was 2.35 in.

By placing observation points in both the top and bottom of the footing, we expected to learn whether or not the shrinkage of the concrete would affect the results. To date no difference in settlement between the top and bottom of the slab has been noted.

A part of the difference between the maximum and minimum settlements shown in Fig. 5(*a*) is accounted for by the greater settlement near the center of the slab. This variation in settlement between different parts of the slab is more clearly indicated in Fig. 5(*b*), in which are plotted the results of averaging separately the settlements of the bolts near the interior wall, of those near the outer wall, and those midway between the walls.

The last four readings show a definite tendency for the smallest amount of settlement to be at the outer edge and the greatest at the center. There may be a question whether or not such a heavily reinforced slab will deform sufficiently to permit greater settlement at the center. It is true that the top of the slab will shrink because of drying, while the bottom will be kept moist by the soil—and this of itself will cause the slab to curl upward somewhat at the edge. However, most of the "curling" is probably caused by an actually greater settlement at the center of the footing.

The Bureau of Engineering Research of the University of Texas expects to continue the settlement observations on the monument for many years and hopes to obtain sufficient data to be of real value. Much of the credit for this research goes to the architect, engineer, and contractor on the monument, all of whom actively cooperated with the bureau by supplying materials, help, and information whenever called upon.

Special mention should be made of Alfred C. Finn and Alfred C. Finn, Jr., architects; Robert J. Cummins, M. Am. Soc. C.E., engineer; and C. A. Bullen, Assoc. M. Am. Soc. C.E., superintendent for the W. S. Bellows Construction Company. In order to advance professional knowledge, they personally sacrificed time for the project when other duties were pressing, and without their help this study would not have been possible.

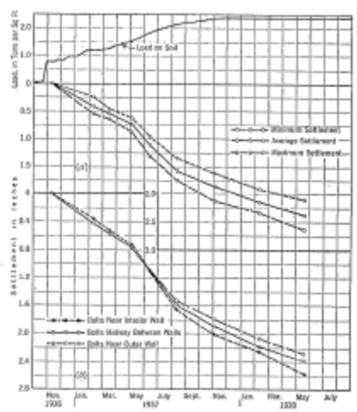



Fig. 5. Settlement Observations on San Jacinto Monument (*a*) Minimum, Maximum, and Average (*b*) Average at Interior Wall, Outer Wall, and Points Midway Between Walls

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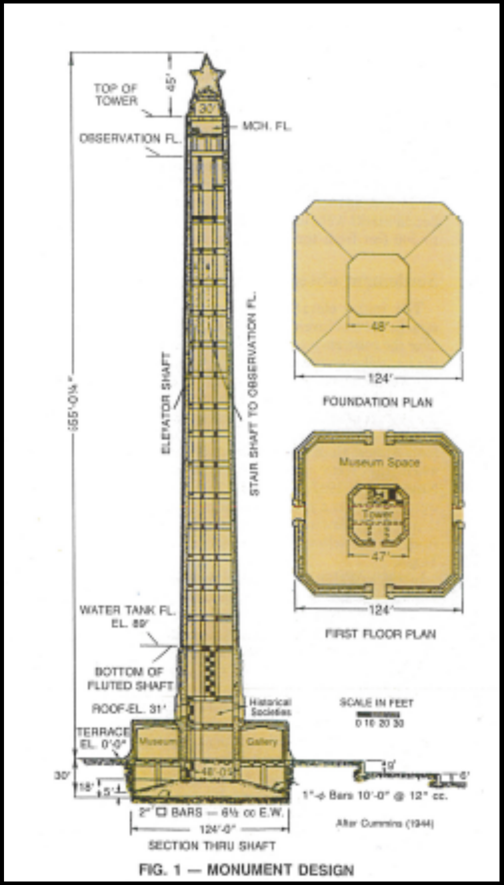
# San Jacinto Monument Mat Foundation SHM




McClelland Engineers Soundings
Winter 1984

# San Jacinto Monument Mat Foundation SHM

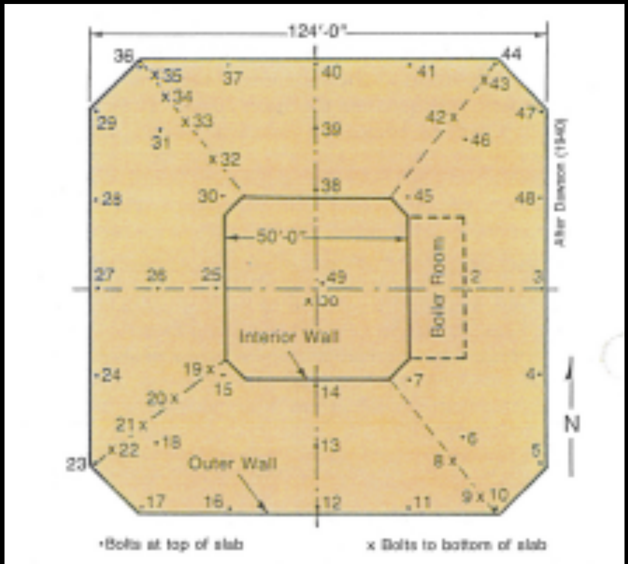



FIG. 3 — LOCATION OF OBSERVATION POINTS

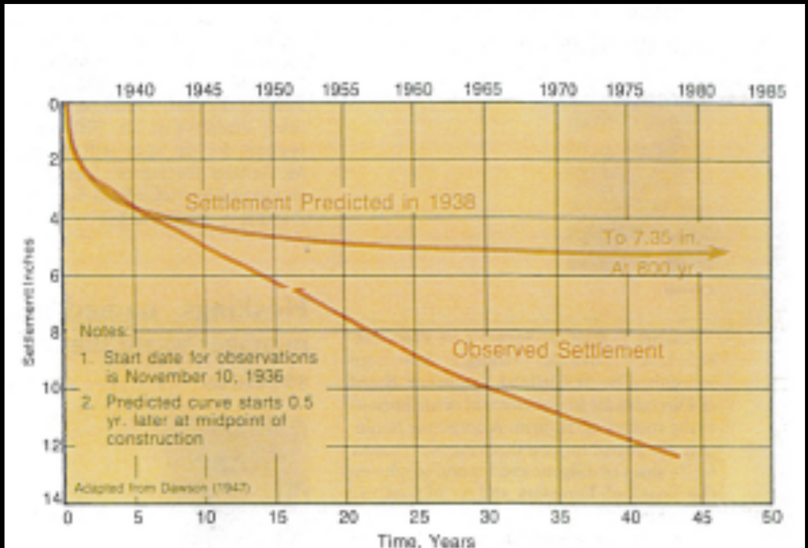



FIG. 5 — PREDICTED AND OBSERVED SETTLEMENT

McClelland Engineers
Soundings Winter 1984

# Objectives of Structural Health Monitoring:
## Farrar and Worden (2007)

1. Modifications to an existing structure,
2. Monitoring of structures affected by external factors,
3. Monitoring during demolition,
4. Structures subject to long-term movement or degradation of materials,
5. Feedback loop to improve future design based on experience,

# Objectives of Structural Health Monitoring

6. Fatigue assessment,
7. Novel systems of construction,
8. Assessment of post-earthquake structural integrity, and
9. Growth in maintenance needs.

# Instrumentation used for SHM

1. Strain gages,
2. Inclinometers,
3. Displacement transducers,
4. Accelerometers,
5. Temperature gages,
6. Pressure transducers,
7. Acoustic sensors,
8. Piezometers, and
9. Laser optical devices

# Instrumentation used for SHM

- Most of these sensors can be wirelessly connected.
- Technology using solar energy is very common in instrumentation.
- Latest technology even has self powered systems, i.e. no external power required.

# Some Recent Work…

# Case History 1

# Health Monitoring of a Stadium Truss During Erection

# Health Monitoring of a Stadium Truss During Erection

- Segmented Erection.
- Monitor strains and stresses at various stages of erection.
- Verification of predicted behavior was needed

# Health Monitoring of a Stadium Truss During Erection

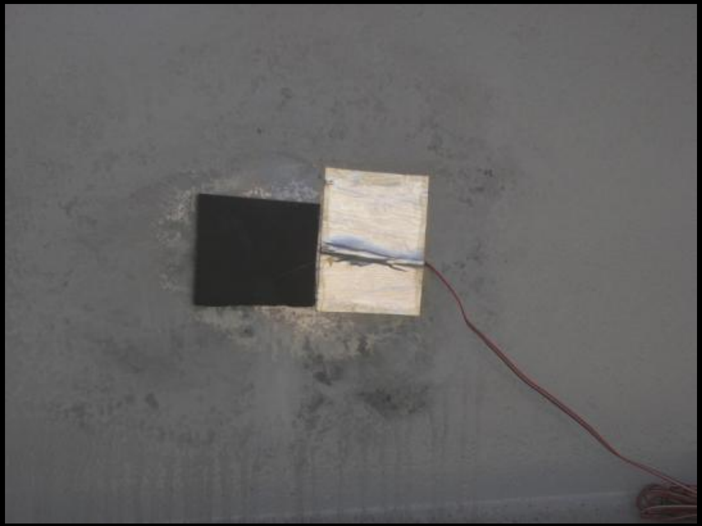
Key Challenges

- Non-interference with the construction schedule.
- No wires were allowed to run from one segment to the other.
- No main power supply.
- No drilling or welding on to the frame.
- Each segment needed to be prepared and instrumented in a narrow 2 day interval.
- No lift access after erection.

# Health Monitoring of a Stadium Truss During Erection

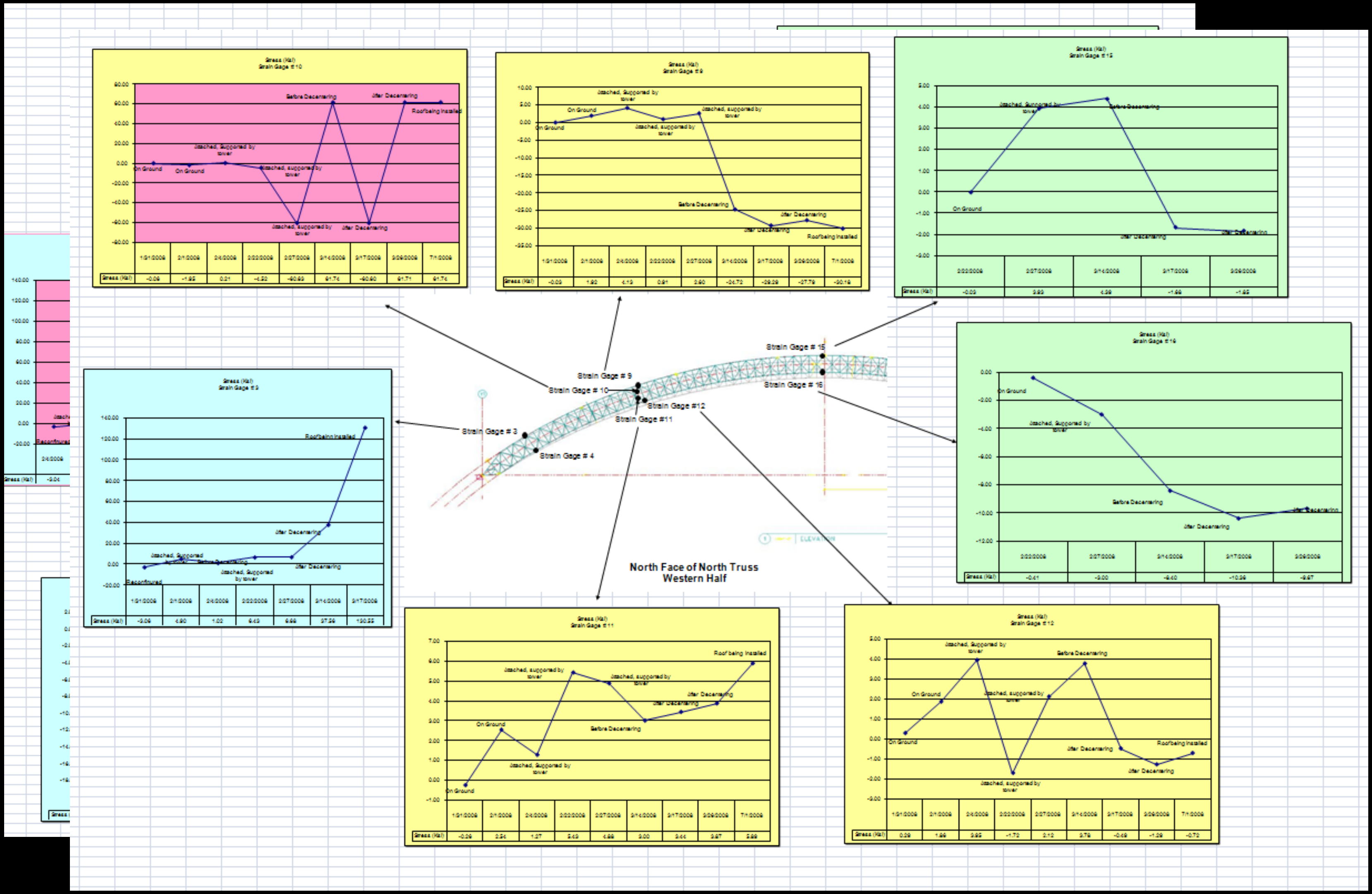
Instruments

- MicroStrain V-Link
  - 4 Strain gauges could be attached to the device.
  - Fully ruggedized for exterior applications.
  - One laptop with data querying software was sufficient to access all boxes.
  - Low duty cycle can give up to 1 year of battery life.



# Health Monitoring of a Stadium Truss During Erection Over 9 Months

# Health Monitoring of a Stadium Truss During Erection Over 9 Months



# Case History 2

# Health Monitoring of a Data Center

# Health Monitoring of a Data Center

- Reinforced concrete high-rise building.
- Raised  access floors.
- Owner wanted to build a fitness center next to the data center.

# Health Monitoring of a Data Center

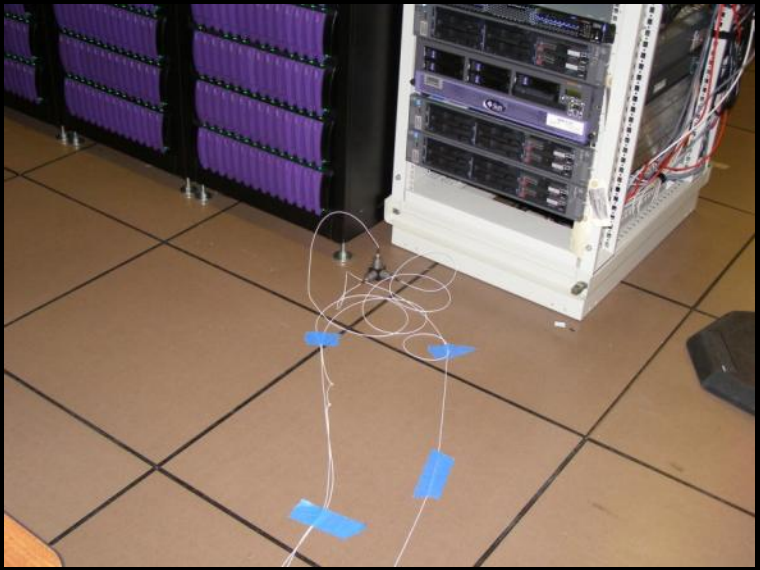
Key Challenges

- Needed to prevent undesirable vibrations in the data center.
- Quantify sensitivities of many high-performance computing systems.
- Needed to inform the contractor immediately upon discovery of an issue.
- Alarm system to alert Walter P Moore and the contractor.

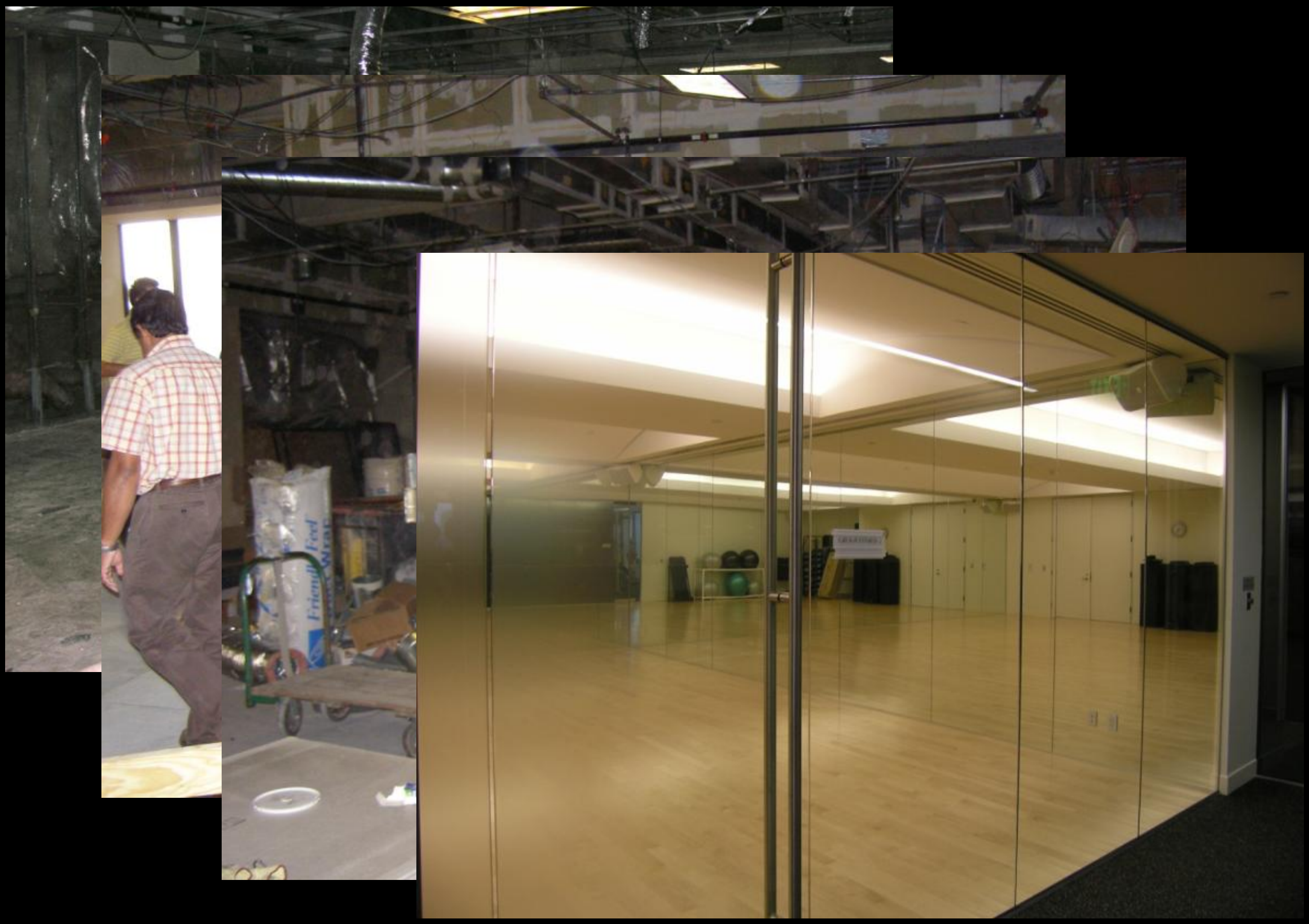
# Health Monitoring of a Data Center

Instruments

- Pre-construction Testing.
  - National Instruments dynamic data acquisition system.
  - PCB $\mu$G scale accelerometers.
- Construction and Operations Time Monitoring
  - Instantel Blastmate device.



# Health Monitoring of a Data Center



# Health Monitoring of a Data Center

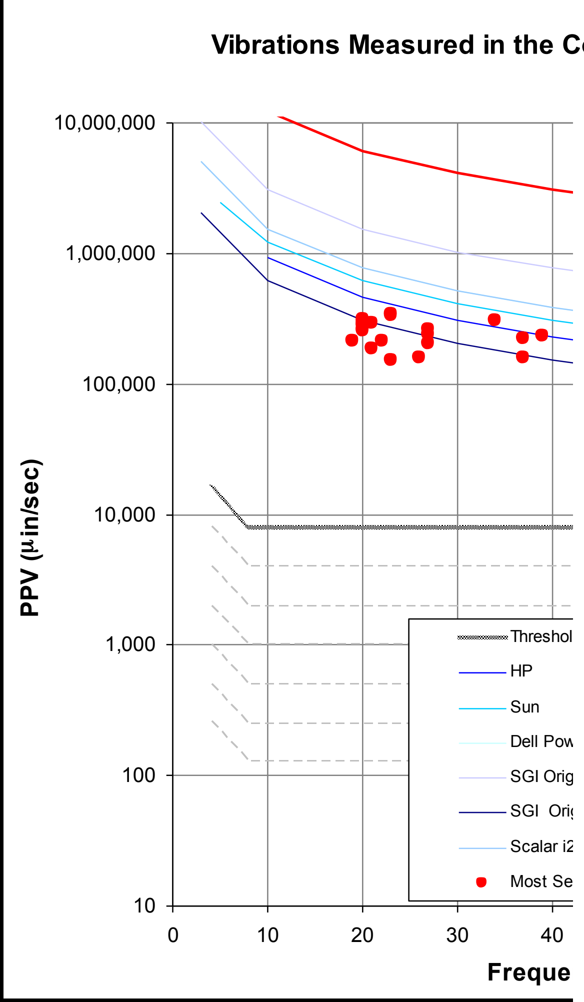


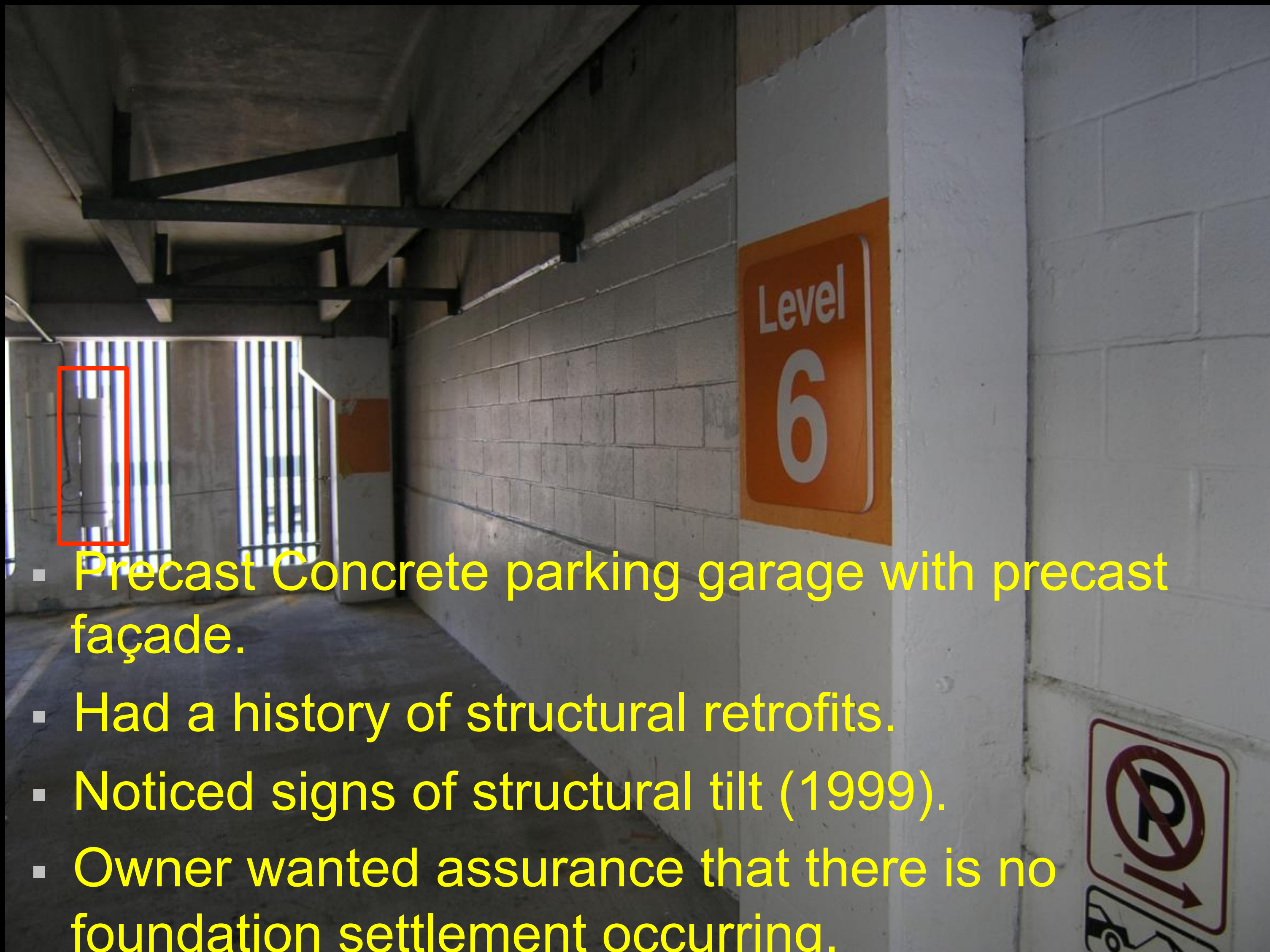

Table 1. Marathon Oil Tower Vibration Testing Summary For November -2006

| Date | Day | Number of Recorded Events | |
|---|---|---|---|
| | | Above 0.02 in/s | Above 0.1 in/s |
| 11/1/2006 | WEDNESDAY | 135 | 0 |
| 11/2/2006 | THURSDAY | 106 | 0 |
| 11/3/2006 | FRIDAY | 32 | 0 |
| 11/4/2006 | SATURDAY | 50 | 0 |
| 11/5/2006 | SUNDAY | 0 | 0 |
| 11/6/2006 | MONDAY | 58 | 1 |
| 11/7/2006 | TUESDAY | 31 | 0 |
| 11/8/2006 | WEDNESDAY | 135 | 0 |
| 11/9/2006 | THURSDAY | 82 | 0 |
| 11/10/2006 | FRIDAY | 25 | 0 |
| 11/11/2006 | SATURDAY | 48 | 1 |
| 11/12/2006 | SUNDAY | 10 | 0 |
| 11/13/2006 | MONDAY | 54 | 0 |
| 11/14/2006 | TUESDAY | 220 | 3 |
| 11/15/2006 | WEDNESDAY | 68 | 1 |
| 11/16/2006 | THURSDAY | 155 | 1 |
| 11/17/2006 | FRIDAY | 11 | 0 |
| 11/18/2006 | SATURDAY | 86 | 0 |
| 11/19/2006 | SUNDAY | 7 | 0 |
| 11/20/2006 | MONDAY | 0 | 0 |
| 11/21/2006 | TUESDAY | 0 | 0 |
| 11/22/2006 | WEDNESDAY | 2 | 0 |
| 11/23/2006 | THURSDAY | 6 | 0 |
| 11/24/2006 | FRIDAY | 8 | 0 |
| 11/25/2006 | SATURDAY | 8 | 0 |
| 11/26/2006 | SUNDAY | 7 | 0 |
| 11/27/2006 | MONDAY | 264 | 0 |
| 11/28/2006 | TUESDAY | 55 | 0 |
| 11/29/2006 | WEDNESDAY | 35 | 0 |
| 11/30/2006 | THURSDAY | 0 | 0 |

# Case History 3

# Health Monitoring of a Parking Garage Structure

# Health Monitoring of a Parking Garage Structure




- Precast Concrete parking garage with precast façade.
- Had a history of structural retrofits.
- Noticed signs of structural tilt (1999).
- Owner wanted assurance that there is no foundation settlement occurring.

# Health Monitoring of a Parking Garage Structure

Key Challenges

- Selection of monitoring location.
- Selection of types of measurements.
- Need to operate during power outages.
- Sensor installation.
- Data logger installation.
- Remote communication setup.
- Alarm system to alert engineer and the client.

# Health Monitoring of a Parking Garage Structure

Instruments

- Campbell Scientific CR10X logger with DC backup.
- Inclinometers with temperature sensors.
- Anemometer.
- Rain gauge.

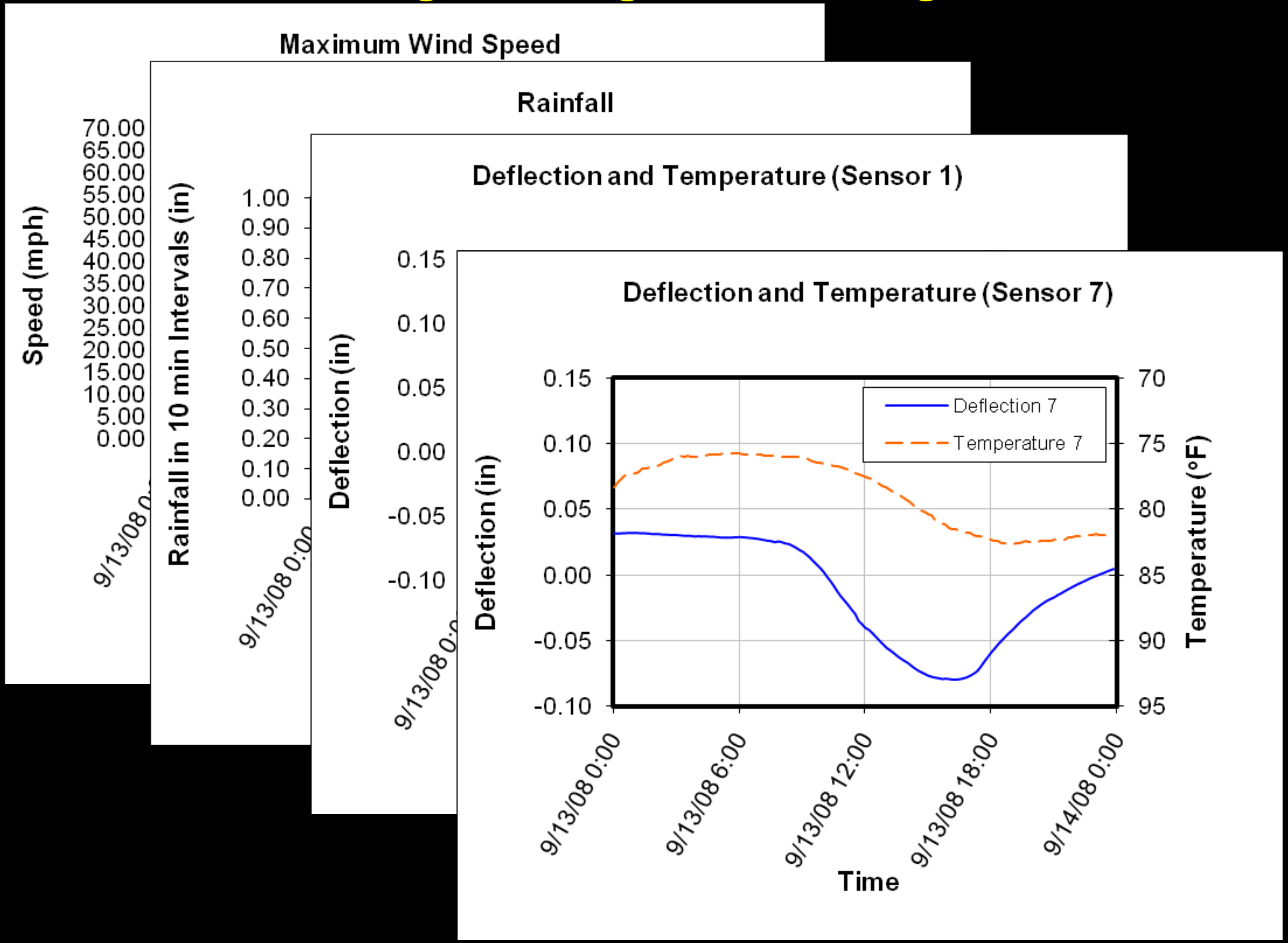
# Health Monitoring of a Parking Garage Structure

Installation

- Sensors on 4th and 7th levels.

# Health Monitoring of a Parking Garage Structure

## Health Monitoring in Progress During Hurricane Ike



# Case History 4

# Health Monitoring of a Bridge Essential to Business Operations

# Health Monitoring of a Bridge Essential to Business Operations

- Precast concrete bridge.
- Business operations will be halted if bridge fails.
- No information was available to rate the capacity.
- No analytical work could be done without exhaustive NDE
- Owner wanted to transport heavy construction material and equipment over the bridge for next 3 years.
- SHM was suggested to monitor the bridge during the heaviest loading phase for 1 year.

# Health Monitoring of a Bridge Essential to Business Operations

Key Challenges

- Installation of inclinometers under girders.
- Access was difficult.
- Night time installation was preferred.
- Installation has to be stopped when a train passed by under the bridge.
- The whole system needed to be run with solar power.
- Remote communication setup.
- Alarm system to alert the engineer and the client.

# Health Monitoring of a Bridge Essential to Business Operations

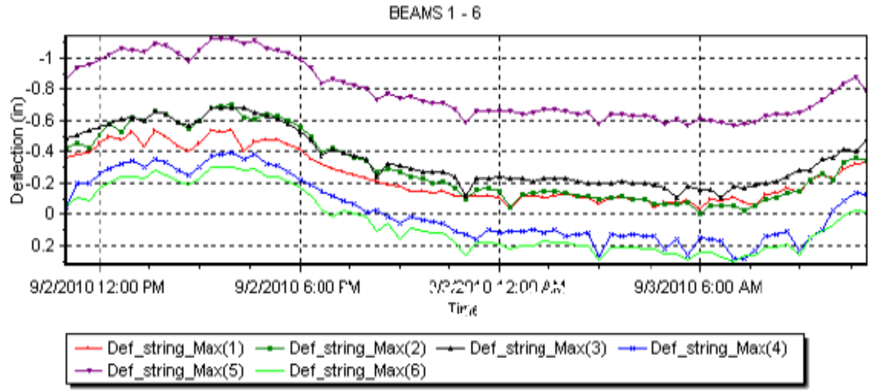
Instruments

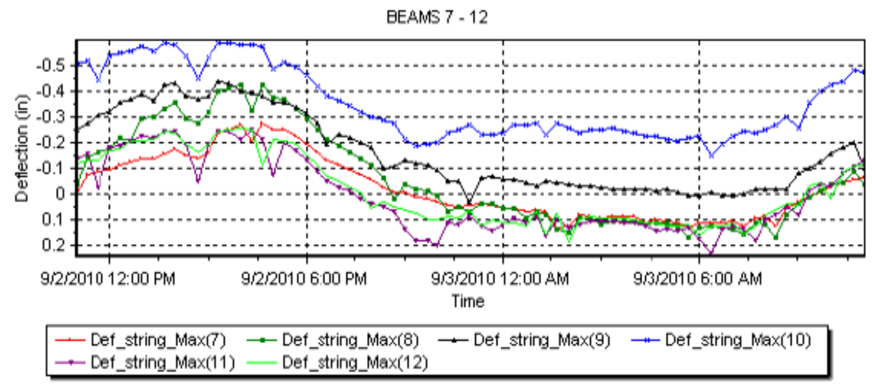
- Campbell Scientific CR1000 logger with solar power.
- Tilt beams with temperature sensors.
- Cellular TCP/IP modem facilitates accessing data over the internet

# Health Monitoring of a Bridge Essential to Business Operations

# Health Monitoring of a Bridge Essential to Business Operations

## Health Monitoring in Progress




| | | | |
|---|---|---|---|
| LAST COLLECTED DATA | | BAT V | 12.9 V |
| 9/3/2010 11:00:00 AM | | Int Temp | 36.7 C |

# Summary of SHM Process

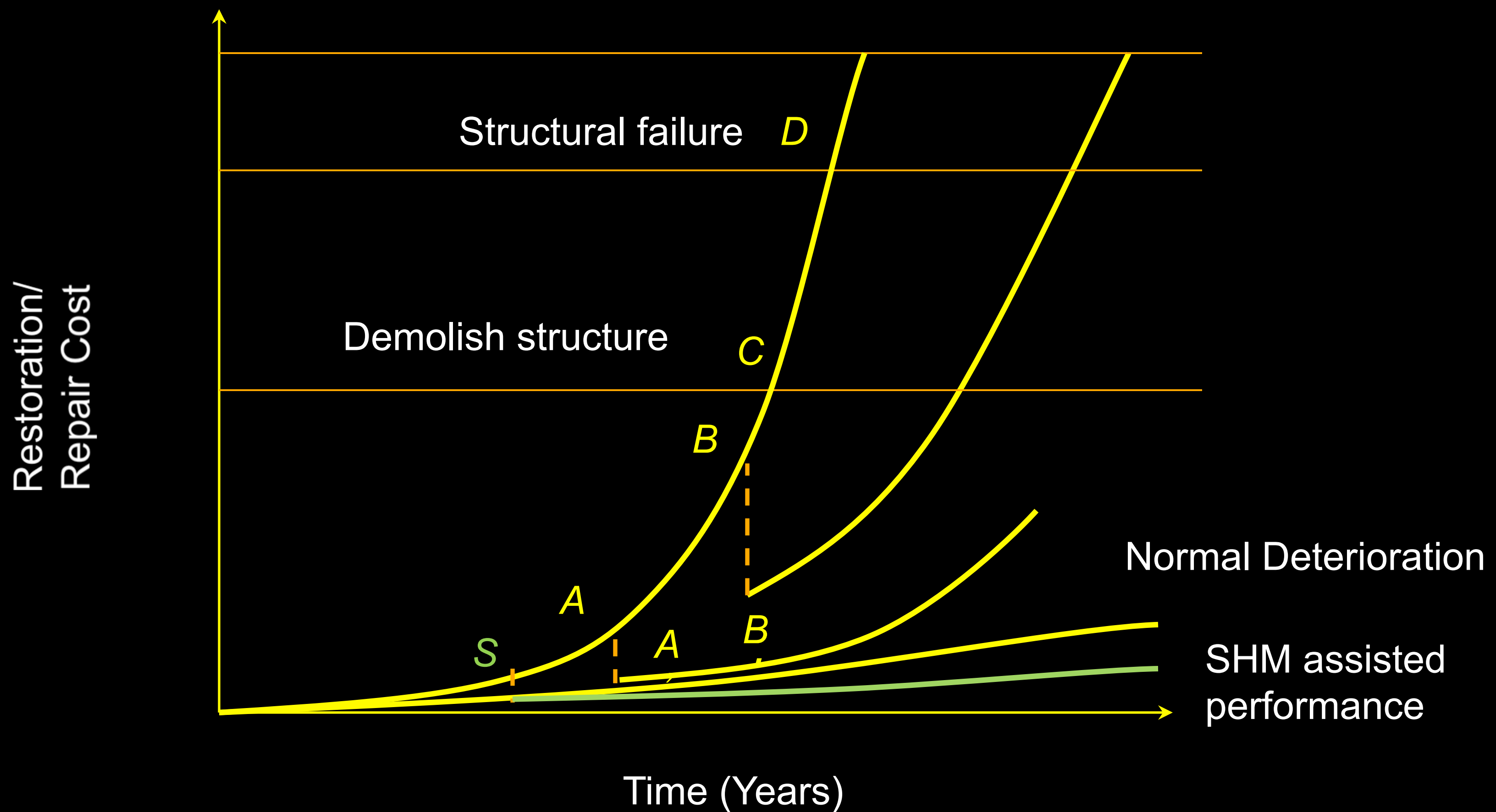
- Evaluate need
  - Discuss the motivation in implementing SHM with the client and the benefits to be accrued
  - Discuss the period of time for monitoring
  - Have a clarity on how the damage or distress is to be defined and measured
- Select the appropriate instrumentation and data acquisition system
  - Environmental conditions
- Extract meaningful data
  - Presentation to client in a meaningful and understandable format

# What is Ahead?

- Reduce the implementation cost.
  - Improved hardware.
  - Extensive usage by the industry.
- Implement wireless and self powered technology.
  - Facilitates usage even in remote areas.
  - Simplifies installation.
  - Insensitive to local power outages.
- Estimate potential savings of using SHM.
  - Develop models to show potential savings in using SHM vs. periodic physical inspections.

# Deferred Maintenance and SHM

## Structural Deterioration Model




*After Chrest et al. (2001)*

*Modified by Prasad and Gosain*

# Monitoring Building Tilt, Bridge Dynamic Deflections, and Floor Vibrations during Construction Activities for Structural Performance and Client Satisfaction

## Questions?


NGosain@WalterPMoore.com

PSamarajiva@WalterPMoore.com

DChoudhuri@WalterPMoore.com

WALTER P MOORE