Reliability Assessment of Temporary Structures Using Past Performance Information

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Outline

- Introduction
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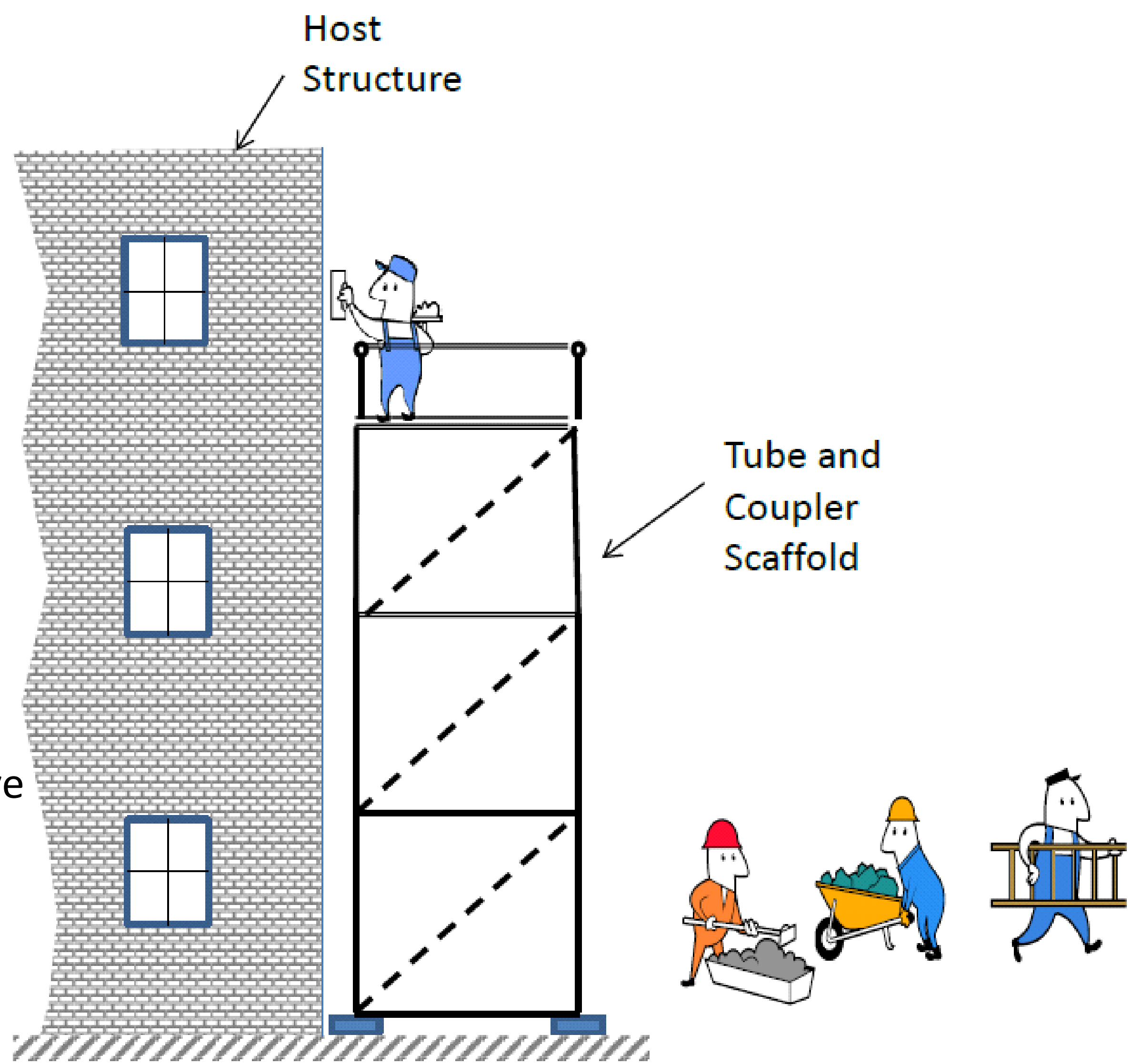
Temporary Structures

- Short service life
- Designed for a lower load
- Often used along a host structure

Examples:

Scaffolds, Shelters, Temporary walkways, Temporary protective systems, stages set up for performances



Potential Applied Loads

(1) Dead load and live load
(2) Wind
(3) Earthquakes

Dead load and live load often do not require any specific treatment

Wind and earthquakes are load types that require more attention.

- These loads are determined based on occurrence rate (average return period for the event)
- Shorter service life of a temporary structure thus dictates using a lower intensity than that used for a permanent system
- Question arises on whether to allow the usage to continue when the service period is exhausted

Alternative decision-making strategies
1. Keep the system up and continue using it.
2. Disassemble the system and reassemble it again, then start using it.

Issues with Alternative 1:
- In terms of the risk of failure, can we assume it is the same as what was considered in the original design in the first usage period?
- Or should we assume the risk of failure is cumulative; and as such, the risk is increased (almost doubled) as we continue into the second usage period?

Issues with Alternative 2:
- Is the risk the same as the system used in the first usage period?
- Will the additional cost justify repeated disassembling and reassembling?

Motivation for Study

The decision-making can well be done using a rational method for arriving a more accurate estimate of the risk considering such factors as:

- The probability for the future occurrences of the event
- Wear and tear of the system (which may affect the resistance)
- Performance of the system as was used in a previous usage period.

The estimated risk provides a determining factor that can be used for making the decision on whether to allow the usage to continue into the next cycle.

The significance of the estimated risk of failure can be benchmarked based on:

- The risk of failure of the host structure for the same service period as that of the temporary structure (in the case of a scaffold that is used for repair)
- The increase in the risk of failure in a new usage period compared with the previous period.
- An accepted risk of failure as the maximum allowable value.

The decision-making may also include suggestions for strengthening the temporary structure if the estimated risk is considered high.

Justification for Study

Incident	Date	Cause of Failure	Location
Scaffold Collapse	July 21, 1998	Faulty Design (Lack of Bracing)	Times Square, New York, NY
Suspended Scaffold Collapse	March 9, 2002	High Wind	John Hancock Building, Chicago, IL
Stage Collapse	August 13, 2011	High Wind	Indianapolis, IN
Stage Collapse	August, 18 2011	High Wind	Hasselt, Belgium

Causes of failure

1. Inadequate design of system components;
2. Inadequate prediction of the type of load prevalent;
3. Underestimation of the system capacity to withstand loads;
4. Natural load effects exceeding the design criteria; and
5. Inadequate erection and coupling of members at joints.

This presentation only considers the potential failure because of loads from wind and earthquakes.

Basic Formulation

The formulation is based on using performance record in a usage period as a basis to modify the risk of failure into a second usage period.

In any given period of usage, the performance of the structure may be explained as two possible conditions:

1. The temporary structure did not experience any major load during its usage; and
2. The temporary structure experienced a major load during its first usage and survived.

With the first situation, the structure performed well and passed its original intended short service life. A new (modified) risk level is obtained based on the fact that it did not experience a major load. This is considered as a performance record and can be used along with a Bayesian approach in modifying the risk of failure of the structure. Let:

θ = the occurrence rate for the extreme load event
ε = outcome of any new information

$$P''(\theta = \theta_i) = \frac{P(\varepsilon \mid \theta = \theta_i)P'(\theta = \theta_i)}{\sum_{i=1}^{n} P(\varepsilon \mid \theta = \theta_i)P'(\theta = \theta_i)}$$

If the probability of failure of the structure for one-time load exceeding the resistance is *p*, during the service time of the structure (*t*), and considering the random occurrence of the extreme events in time *t*, the probability of failure is

$$p_f = \sum_{n=0}^{\infty}[1-(1-p)^n]P(X=n)$$

With *R* the resistance and *S* the load, $p = P(R \leq S)$, or

$$p = \int [1 - F_S(r)] f_R(r) dr$$

Using Poisson distribution for random occurrence of the extreme events,

$$p_f = \sum_{n=0}^{\infty} [1-(1-p)^n] \frac{(\theta t)^n}{n!} e^{-\theta t} = 1 - e^{-\theta p t}$$

Finally, using the posterior probability values for all possible values of the activity rate θ

$$p_f = [1-e^{-\theta_1 p t}] P''(\theta = \theta_1) + [1-e^{-\theta_2 p t}] P''(\theta = \theta_2] + \ldots$$

Example 1:
Original design: 50-year strong wind
First intended service life of the structure : two years
Performance Record: during this period no severe wind loads (in excess of the design load) occurred.

Thus:
ε= "no occurrences within two years"

Considering two possible values for the occurrence rate of strong winds,

θ_1=0, and $P'(\theta=\theta_1)$=2/50=0.04

θ_2=0.02, and $P'(\theta=\theta_2)$=1- 0.04 = 0.96

After updating:

$$P(\varepsilon \mid \theta = \theta_1) = P(X = 0 \mid \theta = \theta_1) = e^{-\theta_1 t} = e^{-(0\times 2)} = 1$$

$$P(\varepsilon \mid \theta = \theta_2) = P(X = 0 \mid \theta = \theta_2) = e^{-\theta_2 t} = e^{-(0.02\times 2)} = 0.9608$$

$P''(\theta = \theta_1)$ =0.0416 $P''(\theta = \theta_2)$=0.9584

For a temporary structure designed for 90-mph wind, using the statistics of extreme values for wind (at the ORD Airport, Chicago, IL), the probability of failure for one time occurrence is p = 0.0012.

Considering the original design and after one period of usage, also using random occurrence of extreme wind during t= 2 years,

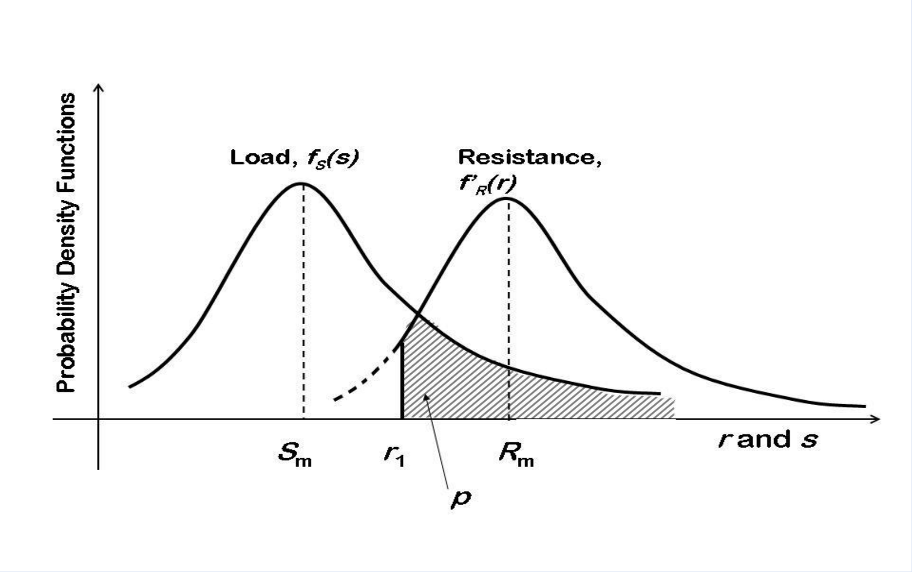
$p_f = 4.8\times 10^{-5}$. and after modifying risk, 4.6×10^{-5}. No appreciable change is observed.

If there is *one* occurrence of the wind storm in the first 2 years; and the structure survives, it can be shown that the modified risk is:
$p_f = 8.25\times10^{-5}$, which is about 70% higher.

Resistance Modification – if a load occurred within the first usage period and the structure survived, the probability density function for the resistance will need to be modified (similar to cases where proof testing is done) for use in computing *p* in the next period. The modified resistance is

$$f_R'(r) = \frac{f_R(r)}{1-F_R(r_1)}$$

$$F_R(r_1) = \int_{-\infty}^{r_1} f_R(r)dr$$



r_1 = load intensity that was applied yet the structure survived it.

Example 2: Scaffold and earthquake load

Original design: for 0.025g (which is for 10% probability in 50 years) at IIT site (based on USGS data)

Usage period: 5 years

Performance : during first usage period: an earthquake occurred and caused a small level of acceleration in the scaffold. However, scaffold survived.

ε = one occurrence in 5 years.

Using the updating process and considering two possible values for activity rates:

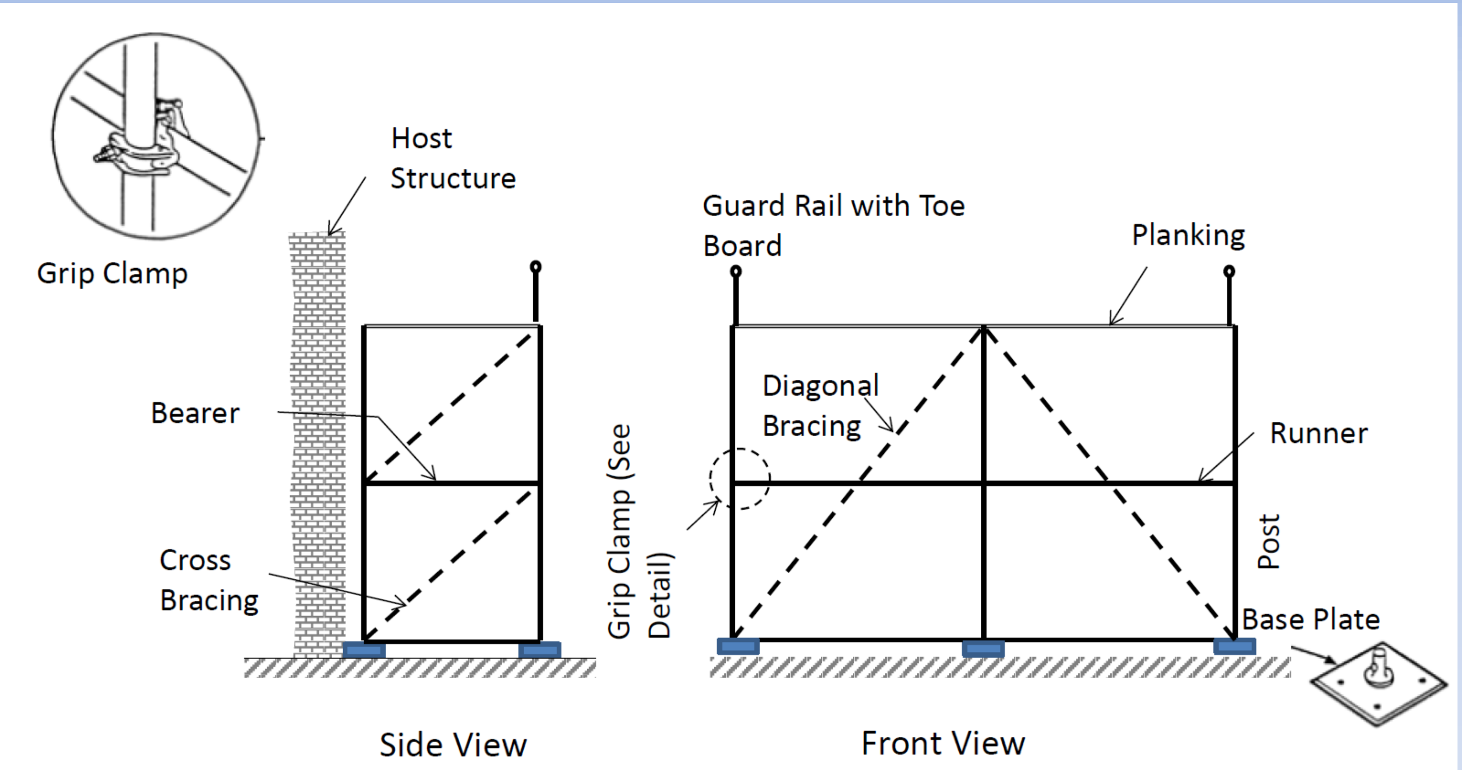
θ_1=1/5, and $P'(\theta=\theta_1)$=5/500=0.01

θ_2=1/500, and $P'(\theta=\theta_2)$=1- 0.01 = 0.99

After updating,

$P''(\theta = \theta_1)$ =0.0360 $P''(\theta = \theta_2)$=0.9640

In order to compute *p*, the resistance of scaffold is needed. This was obtained for tube and coupler scaffolds of various bays and stories.



Prevalent mode of failure: instability (sliding during ground motion)

System overall resistance and risk for original usage period			
Scaffold Configuration	Acceleration Level (*R*) (in g's)	p = P($R \leq S$), Mean S = 0.025g	p_f (for 5 years)*
1-bay, 1 story	0.060	0.0062	6.2E-05
1-bay, 2-story	0.030	0.4105	0.0041
2-bay, 1-story	0.008	0.9994	0.0099
2-bay, 2-story	0.007	0.9999	0.0099
3-bay, 1-story	0.012	0.9820	0.0098
3-bay, 2-story	0.012	0.9820	0.0098

* Considering random occurrence of earthquakes in 5 years

Applied load = 0.025g

Using the posterior probabilities for activity rates, the risk of failure for the second 5-year usage period for 1-bay, 1-story scaffold is
$p_f = 0.000283$,

which is substantially greater than the risk in the first 5-year usage period of $p_f = 6.2E{-}05$.

This increase in the risk may substantiate a necessary action on whether to discontinue the usage of the scaffold in the second period or provide some type of strengthening to make it more stable for application in the next 5 years.

Conclusions

1. Past performance records can be used in a Bayesian updating process to modify the risk of failure of a temporary structure in seismic or wind load environments.
2. The modified risk can be used as a key decision-making parameter in deciding whether to continue or discontinue the use of a temporary structure from one usage period to the next.