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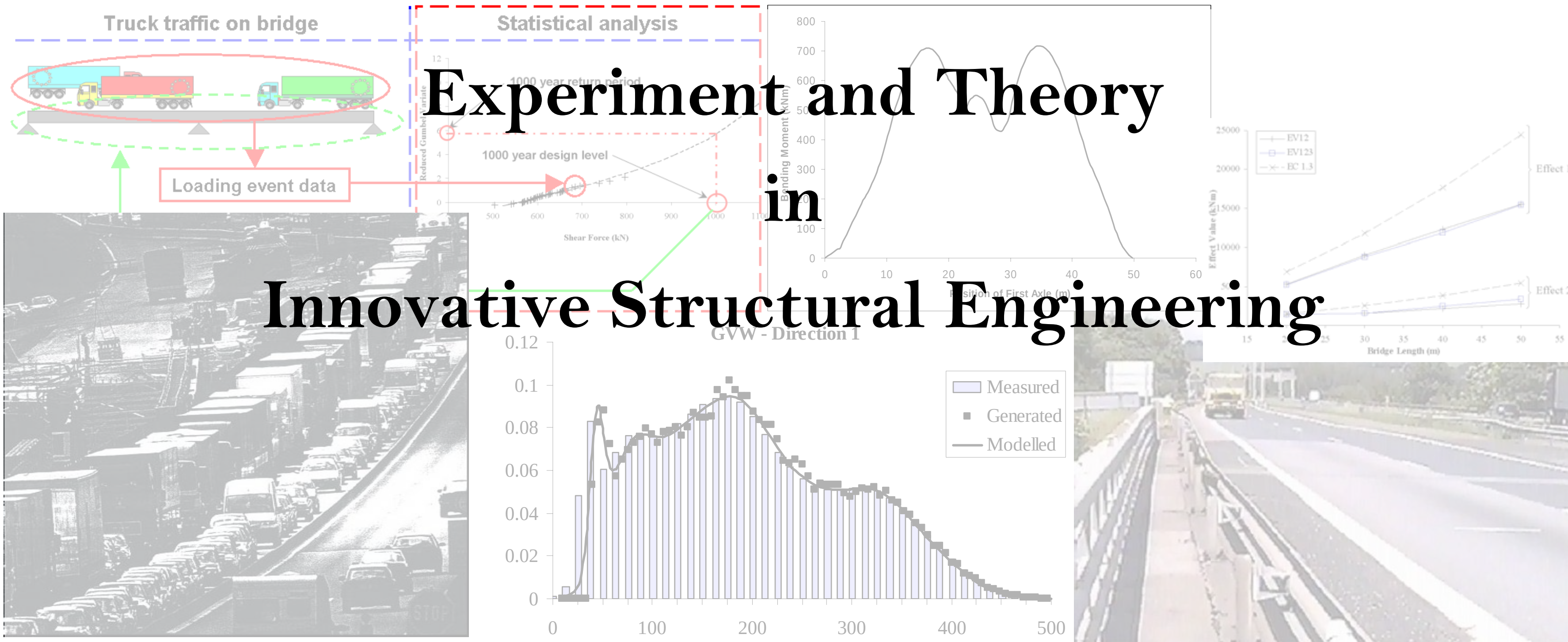
Experiment and Theory in Innovative Structural Engineering



Presentation to Structural Engineering, University College Cork

Introduction

To address the topic, we proceed as:

1. **The definition of Structural Engineering;**
2. **Identify its key elements;**
3. **Briefly examine each element;**
4. **Identify where most future progress lies;**
5. **Show how both theory and experiment relate to future progress.**

Definition of Structural Engineering

Institution of Structural Engineers:

"…the science and art of designing and making with economy and elegance buildings, bridges, frameworks and other similar structures so that they can safely resist the forces to which they may be subjected"

Prof. Tom Collins, University of Toronto:

"…the art of moulding materials we do not really understand into shapes we cannot really analyze so as to withstand forces we cannot really assess in such a way that the public does not really suspect"

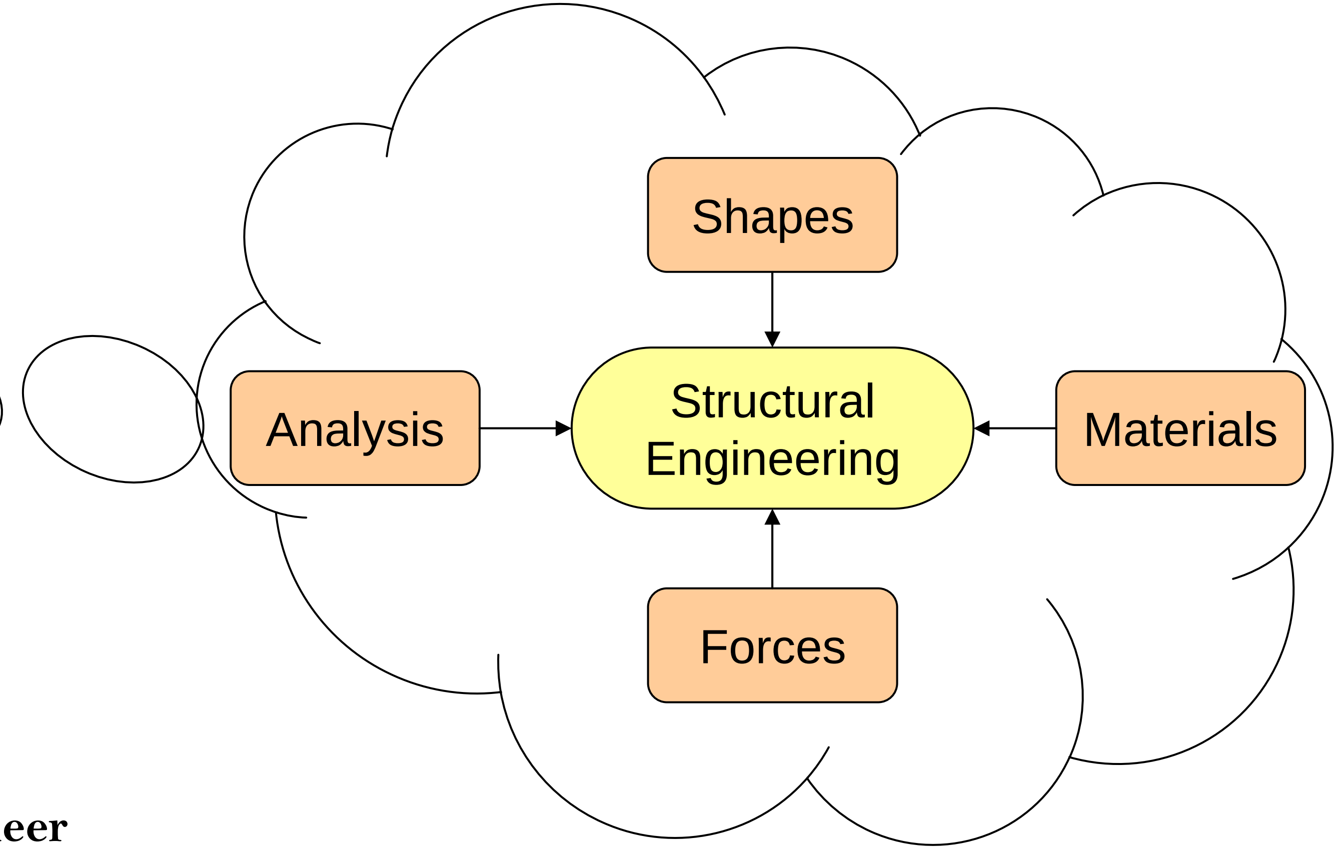
Which is more apt?

And which tells us more about where we need to go?

Key Elements

Identified as:

The Structural Engineer



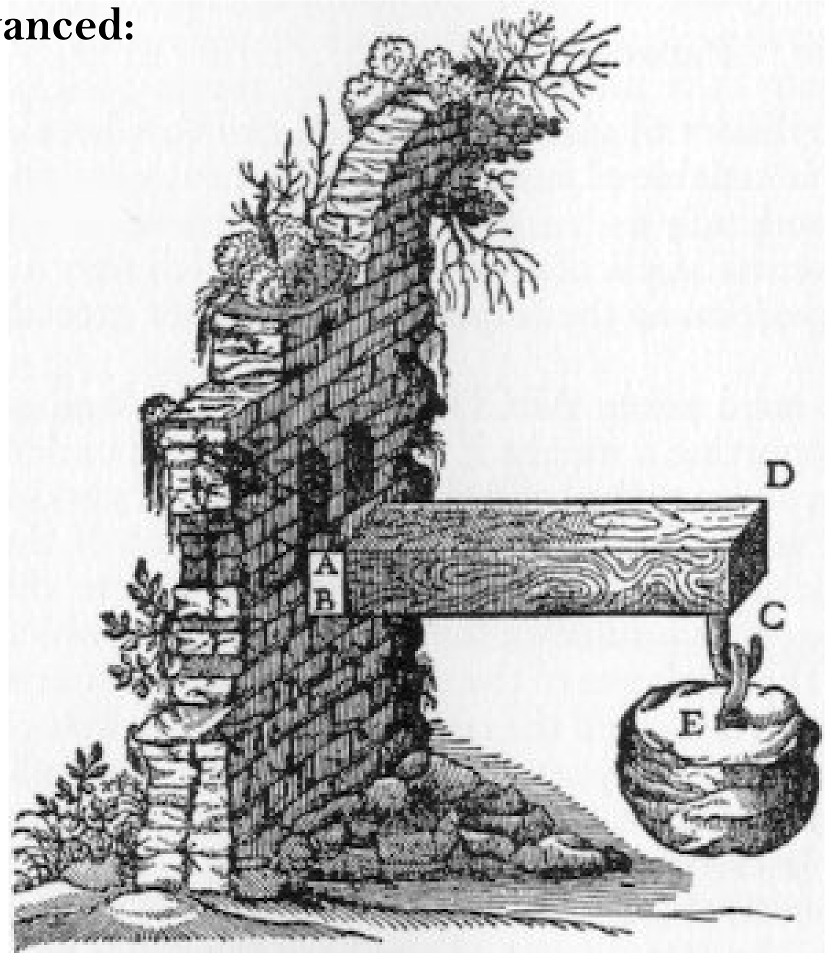
The Design Process

Analysis of Structures – Background

Since Galileo used Hooke's Law, we have advanced:

- Euler-Bernoulli beam theory;
- Coulomb's analysis of arches;
- Clayperon's theorem of 3 moments;
- Mohr's thereoms;
- Theory of Elasticity;
- Moment Distribution;
- Plastic Analysis;
- Computer methods of structural analysis.

…all leading to: The Finite Element Method



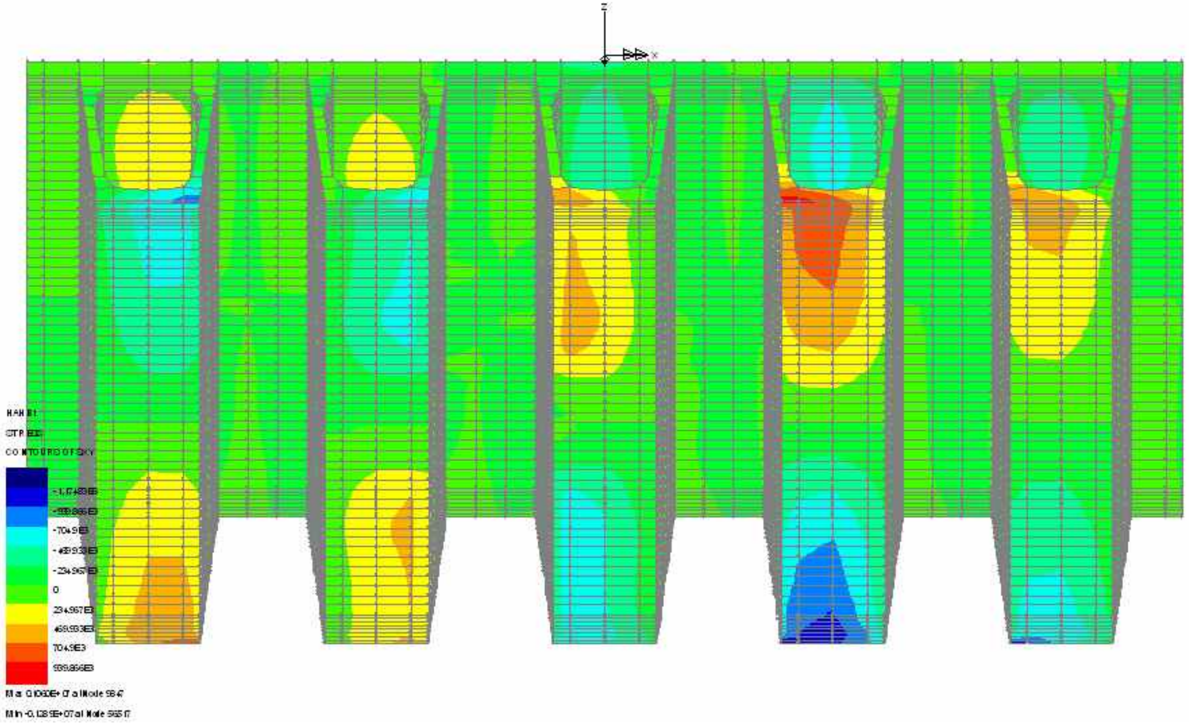
Analysis of Structures – State of the Art

Given:

- arbitrary geometry;
- stipulated loading, and;
- boundary conditions,

finite element analysis:

allows us to solve for all stress resultants to any desired degree of accuracy.



Therefore, has the analysis of structures essentially reached its peak?

Are advances in such areas as mesh generation, new elements and material models simply 'polishing the diamond'?

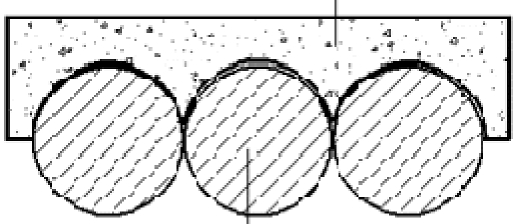
Materials

In the past, materials' development depended on:

- **scientific progress in materials;**
- **the industry's needs;**
- **appropriate analysis methods;**
- **the development of design rules.**

Are today's materials the limit?

- **Production economies of scale;**
- **Code development;**
- **Future scientific development.**



What about new applications of existing materials?

Shapes

Structural geometry is a function of:

- Architect's/Engineer's vision;
- Material limitations;
- Analytical limitations.

Are we now only limited by the vision?

Material limitations:

- Flexibility of concrete;
- Strength of steel;
- Beauty of structural glass.

But: for some recently proposed bridges, composites will be needed:

e.g. Messina Strait's Bridge

Analytical limitations:

FE has removed most.

But: computer limitations remain:

e.g. large nonlinear analyses.

Forces

Institution of Structural Engineers:

> ***"Structures…must safely resist the forces to which they may be subject."***

But what forces does nature impart to our structures?

We can identify the types:

- **Environmental loads (wind, snow, temperature, etc.);**
- **Imposed loads (people, traffic, furnishings etc.);**
- **Dead loads (self weight, superimposed dead loads etc.).**

But what about the actual values?

- **Currently a mix of measurement, statistics and tradition.**

Summary of Key Elements

- **Analysis of Structures:**

  Unlikely to have major advances, but improvements are possible.

- **Materials:**

  Reached an economical plateau, but new materials will be required.

- **Shapes:**

  Limitations are less and less; more so with increasing computing power.

- **Forces:**

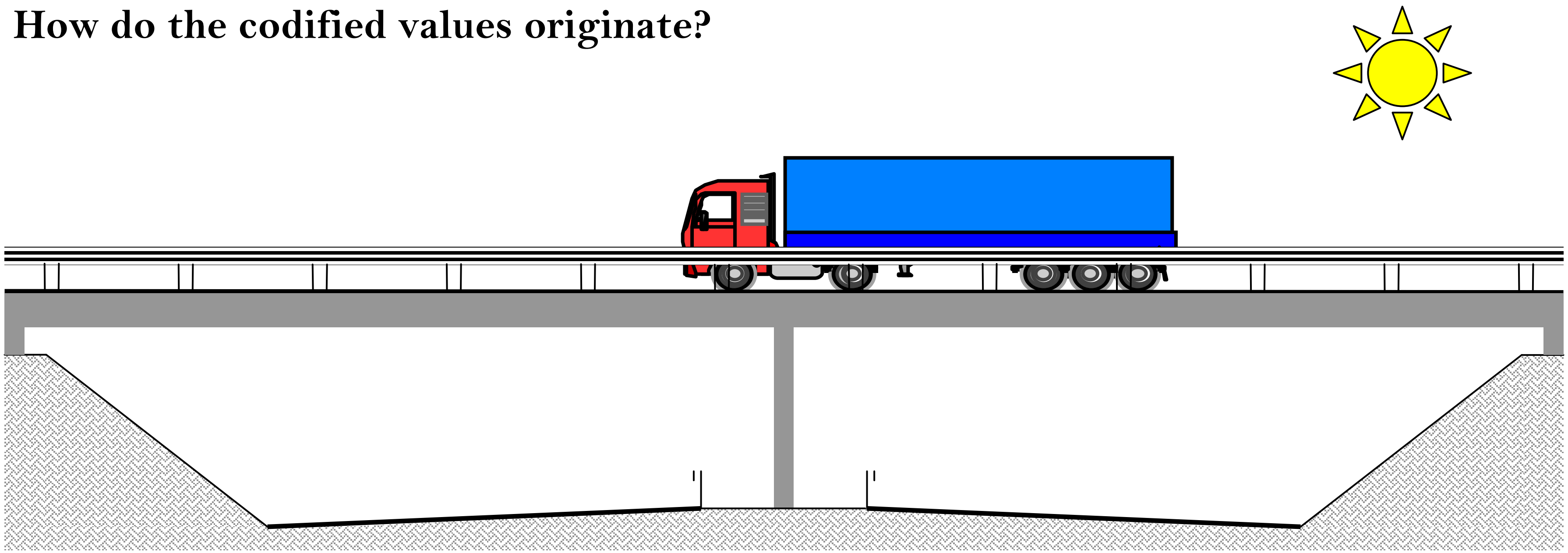
  Poorly estimated: only recently has begun to receive proper attention.

Thus: Most innovation is both possible and required in Force Identification.

Forces – Example

The bridge structure below must be designed for many forms of force.

How do the codified values originate?



Using bridge traffic loading as an example, the use of theory and experiment in the key element requiring innovation is examined.

Initial Measurement

Knowledge of the phenomenon is a prerequisite to the development of a theory.

Measurements are required to identify:

- **Critical and incidental variables;**
- **Approximate bounds on the values.**

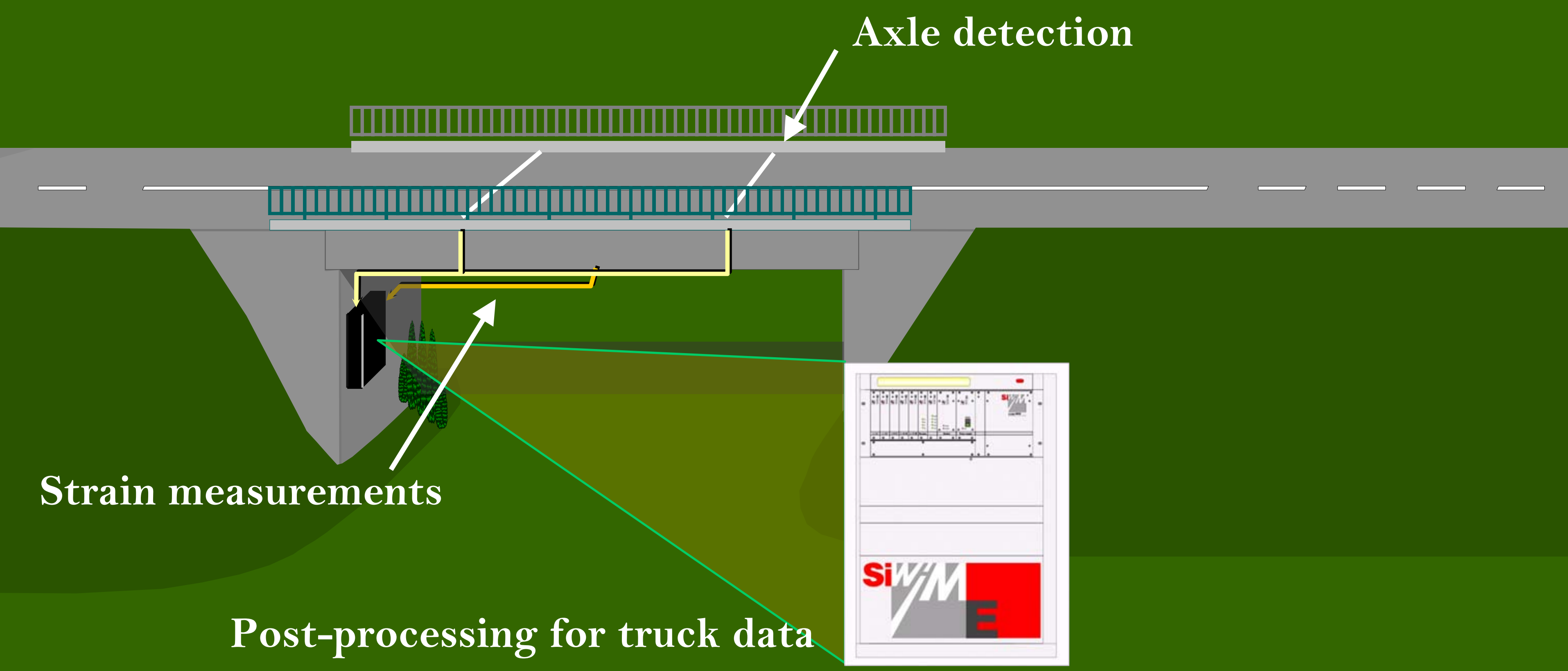
In bridge traffic loading:

Weigh-in-Motion is used to collect truck data, such as:

- **Gross Vehicle Weight;**
- **Configuration, axle-weights and spacings;**
- **Speed and headway or gap to vehicle-in-front.**

Using influence lines, ‘measured’ load effects can then be determined.

Weigh-In-Motion



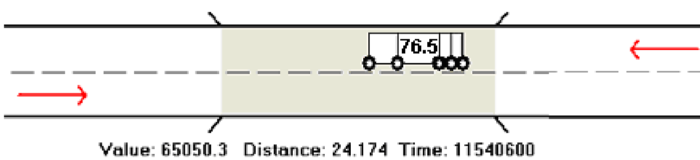
Development of Theory - I

The **basis of the theory** is in the measurements:

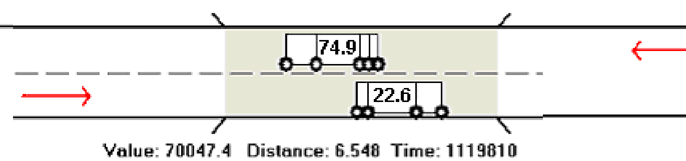
- **Trends** in the data can now be identified;
- **Variables** can be classified as critical or not;
- The **approximate results** of the theory are known.

In bridge traffic loading:

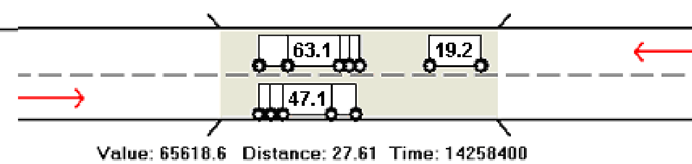
Different forms of loading event exist:



1-truck



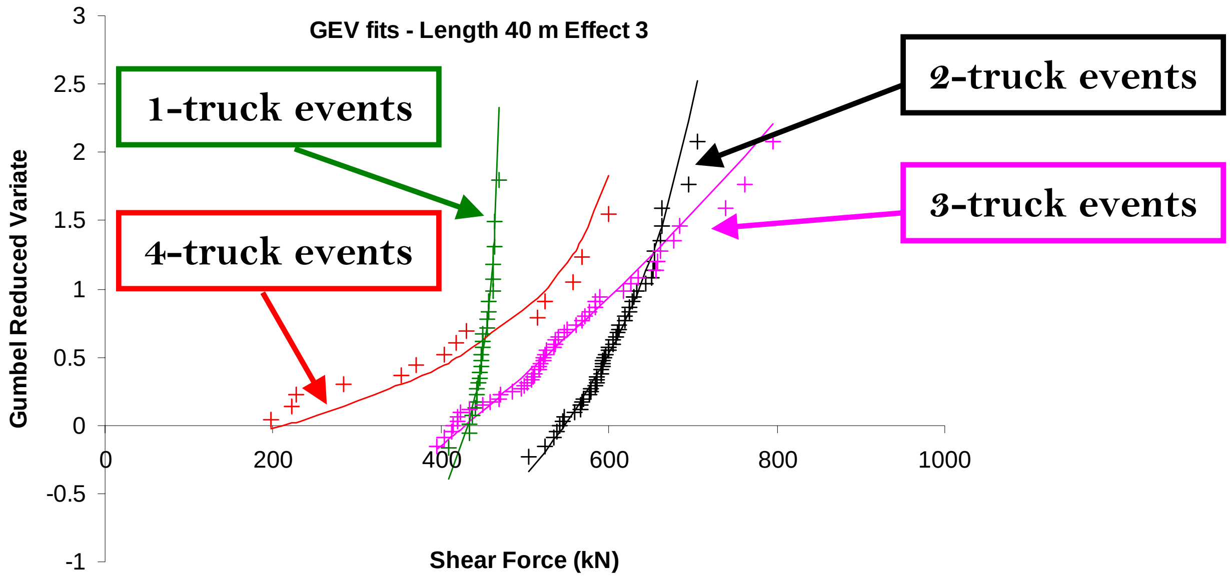
2-truck



3-truck

Development of Theory - II

And these loading events have different distributions:



Thus a new composite distribution of load effect was developed:

Composite Distribution → $G_C(z) = \prod_{i=1}^{N} G_i(z)$ ← Individual Event-type Distribution

Development of Theory - III

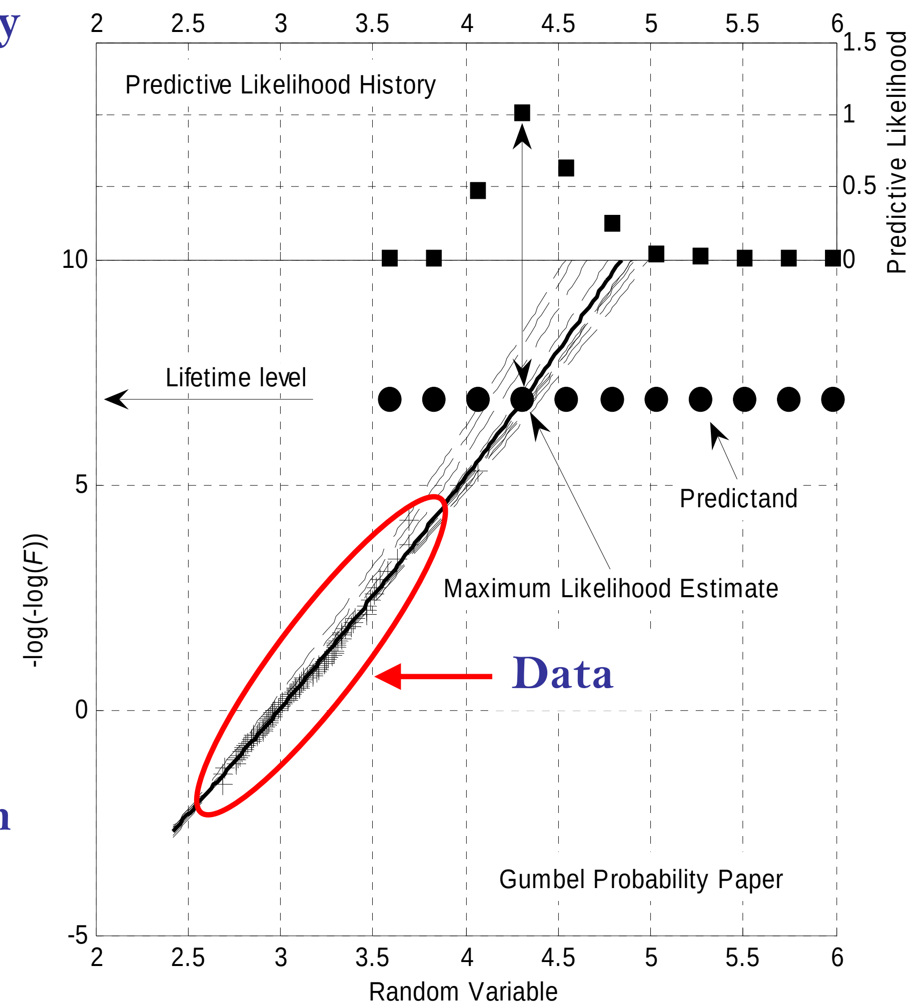
Introducing the existing statistical theory of predictive likelihood:

- the variability of the design loading is estimated;
- confidence in the result is quantified.

Predictive Likelihood:

$$L_P(z \mid y) = \sup_{\theta} L_y(\theta; y) L_z(\theta; z)$$

Best fit of known data & possible prediction



Experiment I

The developed theory:

- must match the initial measurements;
- is applied to new data and/or known problems;
- is ‘pushed’ outside its original scope to observe its behaviour.

Each of these steps is experiment, of one form or another.

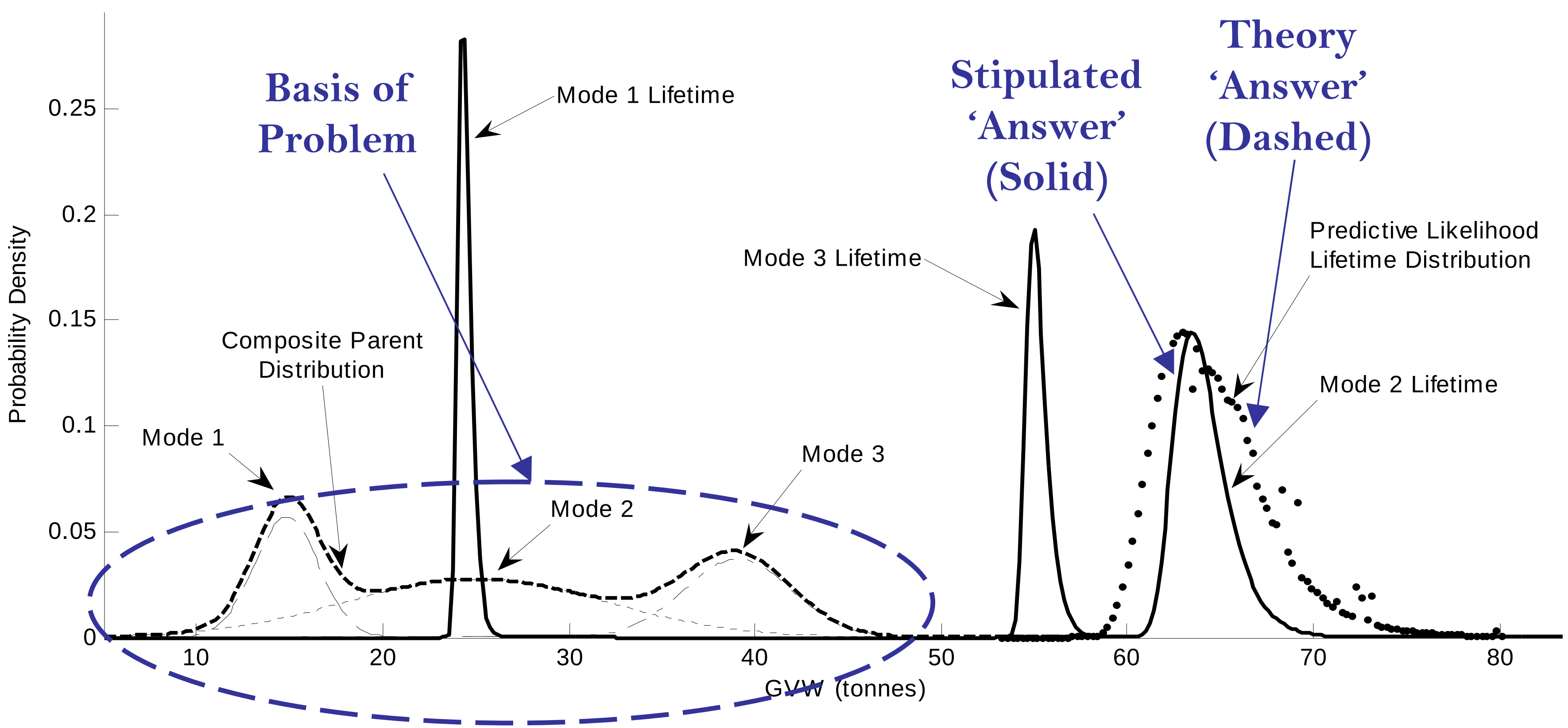
<u>In bridge traffic loading:</u>

The developed theory is applied to a stipulated problem of GVW prediction:

- The final result is the starting point, from which data is ‘simulated’;
- The theory is applied, and we hope to arrive at the starting point.

Experiment II

A known lifetime GVW is predicted using the theory:

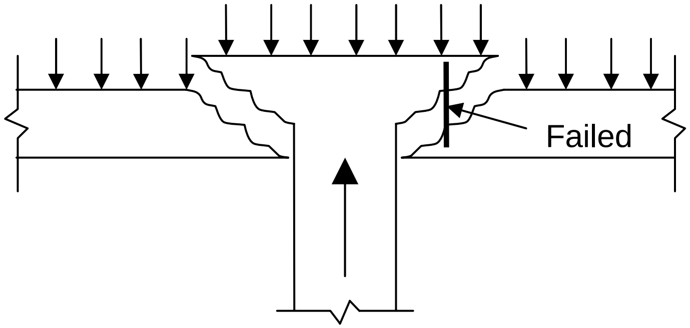


Experiment III

Experimental results must be used to further refine theory when the need arises.

Given that nature is the best laboratory, it seems strange that we do not monitor (experiment) more structures.

The analysis of failures is an experiment in retrospection. But the circumstances of such investigations are not usually amenable to 'spreading the knowledge'.



Conclusions

- The key area for major development in structural engineering is identified;
- Bridge traffic loading is used as a pertinent example;
- The marriage of theory and experiment is described;
- Cross-disciplinary research is shown to help considerably.

In general, future innovation will come from:

- more extensive monitoring of new and existing structures;
- the adaptation of existing theories in other fields;
- the refinement of current analysis methods.

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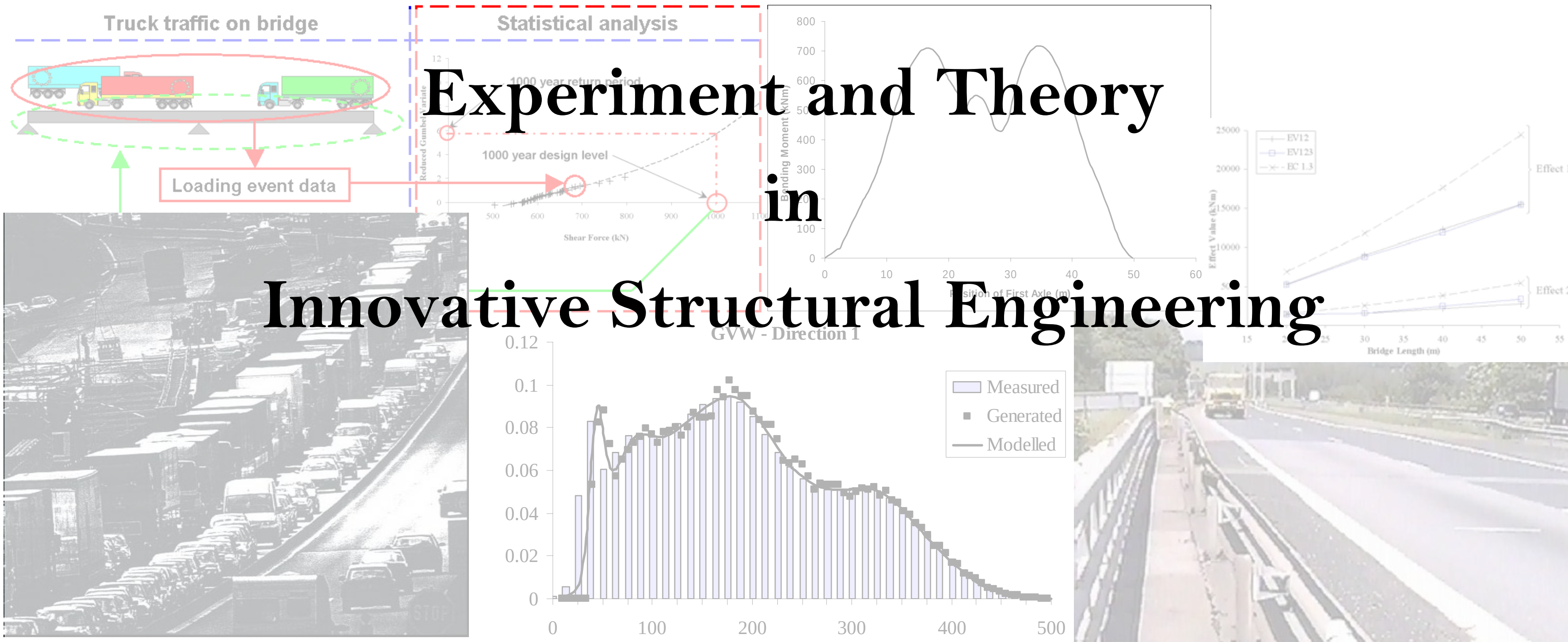

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