The reliability of our Engineering Process: Reliable or not?

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Summary

This paper describes the engineering process in general with specific emphasis on engineer's judgement in relation to the reliability of the engineering process. Judgement components lead to the SLS and ULS analysis process where significant differences in reliability are highlighted both theoretically and from practice. It is presented that a more reliable SLS analysis is a must and actions for improvement are presented.

Keywords: Engineering process, reliability, SLS, ULS, criteria, monitoring.

1. Introduction

Civil and structural engineers demonstrate a wide variety of tasks and activities within the broad context of the construction industry. Their core responsibility however is to develop concepts and detail structures which comply with accepted safety standards, are durable and sustainable, demonstrate fitness for purpose and are balanced in relation to their environmental impact.

A vital tool to make this process happen is engineering judgement: an analysis is mirrored against criteria, experience from the past and commonly accepted state-of-the-art understanding. This paper will give focus on the analysis versus criterion judgement and the value of such judgement given the reliability thereof.

2. Engineering Judgement Components

To judge, one needs components which are considered in terms of their meaning: do they really cover a specific phenomenon, are they reliable. The components are then mirrored against each other. Engineers have a tool box of fixed and firm rules to judge but actually assurance is given by experience. The components which have to be judged in civil engineering are the analysis and the criteria.

2.1 The analysis

In the analysis a concept is simplified into a static scheme with material properties subjected to loads and actions. Given the aspects to be judged it is common practice to consider a Serviceability Limit State and an Ultimate Limit State. Available tools consist of highly professional models and an impressive calculation power which do enable almost any deterministic approach and an increasing penetration in the field of probabilistic analysis techniques.

2.2 The criteria

A wide range of criteria is available (and partly under development) ranging from:

- Very general to quite specific;
- Basic criteria to worked criteria:

  If a phenomenon is too complicated to be covered by calculations, worked criteria have been derived from the basic criteria to allow easy access.

Criteria have been developed for both the SLS and the ULS but also partial safety factor design and probabilistic analysis techniques required additional criteria.

2.3 Judgement

The skills of the engineer and the reliability of the components dominate the quality of judgement, in other words the reliability.

The component's reliability becomes transparent if the results from theoretical desk work is compared with what we can learn from the real world. What we can learn is heavily influenced wether the considered aspect is a factored or unfactored condition.

Figure 1 gives a brief overview of the judgement components.

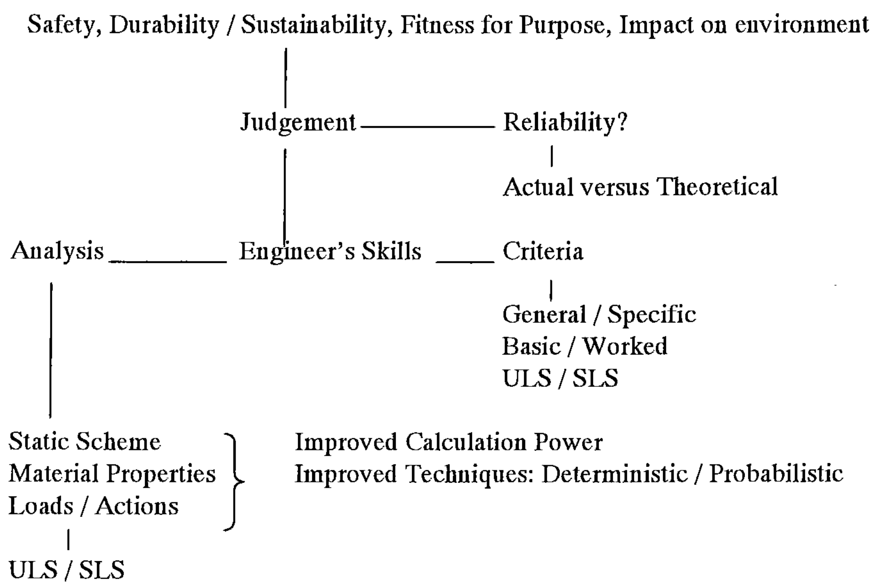

Fig. 1: Judgement Components and Influencing Factors

3. Engineering Judgement, Strength and Weakness

Engineers need skills to judge. This is obvious and an open door. Nevertheless it's an issue which appears to require due attention in the professional community of structural engineers. The two components, analysis and criteria, will be further investigated to conclude strength and weakness aspects.

A helpful tool is a comparison between the flow schemes of the SLS and ULS which are in terms of flow scheme basically the same but show significant differences once the areas of uncertainties are indicated (fig. 2 and 3). The shaded areas of uncertainties indicate weakness in our engineering process.

4. Serviceability Limit State, uncertainties

Loads (including actions) are uncertain for quite a variety of structures, especially in heavy civil engineering. The loading schemes do allow a structural analysis but their value to analyse the actual response of the structure is limited. As load values and loading schemes tend to be an overestimation of actual conditions, the anticipated response often appears to be beyond the actual response. This might be considered as satisfactory but is doubtful once the SLS check appears to be covering. From practice it is known that this is frequently the case for link spans in heavy civil marine engineering where blanket uniform distributed loads are used to check deformations, although facilities aren't open to public and won't receive a blanket load. More impact have deformation criteria applicable to retaining structures where blanket loads and water head differences are highly uncertain: The applicable criteria often appear to be governing.

Static schemes have appeared to be reliable tools, but as soon soil-structure interaction comes in the picture, the reliability becomes a point of concern. Foundationpile-soil interaction is normally modelled by multi linear, elasto-plastic springs, as such not reflecting the coherence of the soil. The required three dimensional finite element models, with due allowance for dynamic response, are still beyond the present state of the art.

It may be clear that concluded performance can be assessed but that the reliability thereof is doubtful for a variety of concepts.

In case of overestimation of the response it violates the economy of structures. In case of underestimation minor to major consequences might arise. In both cases it obstructs our understanding of structures and the reliability of the analysis and as such a further development of techniques.

In the selected aspect box highly uncertain aspects are grouped together and appear to be complicated in heavy civil and marine engineering. Common aspects are deflections, rotations and crack width. Where deflections are governing, special attention is required as deflection on it's own doesn't mean so much. Underlying aspects of own frequency and discomfort by accelerations often disappear although once were a reason to set these deformation criteria to easily approach the more complicated dynamic response. As specifications tend to be kept frozen where concepts have developed in terms of spans, materials and configuration, it is clear that the worked specification does not necessarily cover the basic phenomenon.

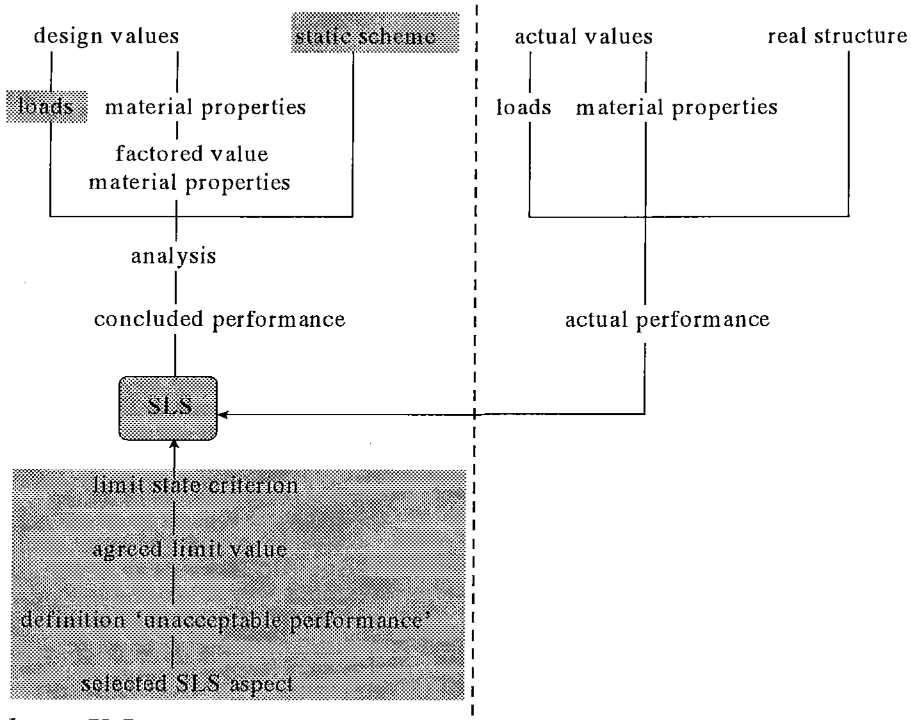

Fig. 2: Flow Scheme SLS

Rotation

Loading platforms in the oil and gas industry are often equipped with so called Loading Arms: Fixed risers with rotating arms which support the product lines to be connected between the platform and the ship.

Until recently extreme tight specifications for the rotation of the loading arm base plate were applicable: 0,001 radian under maximum working load. What such a specification means in terms of concept, material demand and detailing was recently experienced during detailed design of a large marine terminal.

Consequences of this SLS requirement were experienced unrealistic, but nevertheless had to be taken. Research proved that the basis of the criterion was unclear. Where originally pipe stresses at the connection interface with the manifold were considered to be the originator, it appeared in the end that stability aspects of the hinge between riser and arms were the trigger for this specification. This aspect has been worked out, in the past, into a requirement more easy accessible for an analysis, but drifted away from the requirement to be satisfied. After some research a significant relaxation of the rotation criterion could be justified.

Crack width

The ongoing discussion about the significance of specific crack width limitation in relation to the durability of structures and the aspects regarding the validity of crack width calculations is considered to be well known and not further dealt with in this paper.

5. Ultimate Limit State, uncertainties

In the ULS we have to deal with uncertainties as well, especially from the direction of loadings. But contrary to the SLS where the real world demonstrates the actual performance of integral structures, the ULS is more of a numerical system, where factored aspects are combined or compared. We know from decades long experience that the allowance made by factored loadings is satisfactory. Our perception of safety and, more in detail, our present standards related to probabilities of exceedance are founded on this experience.

It is therefore that the ULS analysis, as applied at present, provides the engineer a significant tool. Contrary to the ULS where the factored aspect counts, it is the value of a contributing factor that gets an 'absolute' meaning in the SLS analysis.

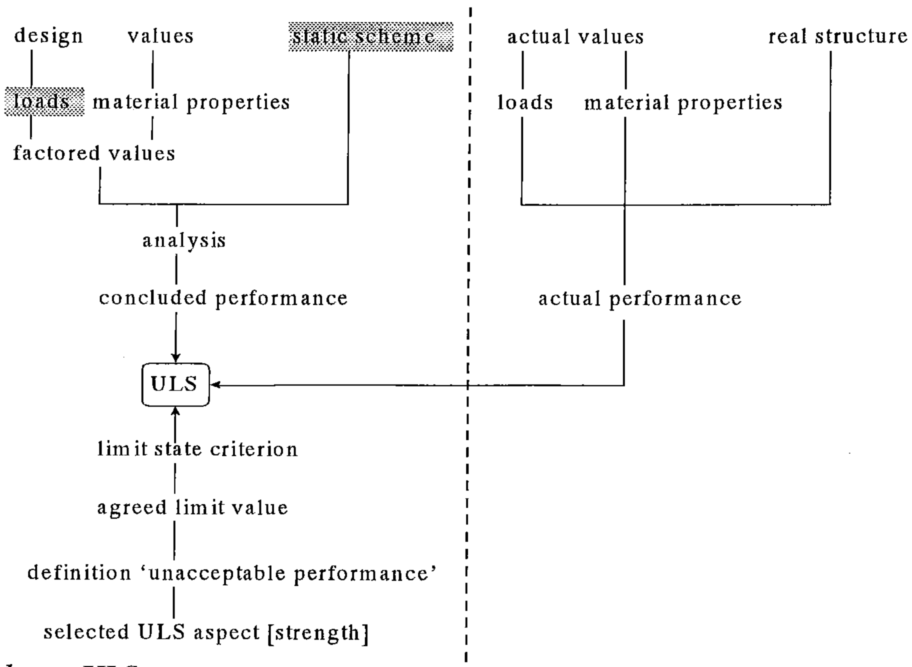

Fig. 3: Flow Scheme ULS

6. The Engineer's Judgement, adequate input.

As discussed above, engineers may suffer from the deficiencies of the present SLS state of the art. Not because of the process itself, but because of the reliability of input data and the applied criteria .

To carry out his core tasks, the engineer should have access to a reliable SLS analysis: it is a must to demonstrate compliance of his concept with functional requirements. Also the ongoing ability to describe the structure's performance from an IT point of view will continue and will ask for a civil engineering response in terms of understanding structural performance and development of adequate criteria, also for the SLS.

7. How to proceed

The SLS analysis is a must and can provide the engineer a tool he requires.

At present the performance is disappointing mainly because of input parameters and applied criteria which often inadequately replace the underlying phenomenon.

Improvement of significance of the SLS analysis could be achieved as follows:

- A careful examination of aspects to be included in the SLS analysis and subsequently to the development of SLS criteria, which are accessible to engineers to process.
- Where the SLS aspect is replaced by worked criteria, an indication of validity limits would be appropriate.
- It is anticipated by the author that domain specific SLS rules might be required.
- Research and assessment of realistic loadings for the SLS analysis. At present the ULS loads are often factored SLS loads. Given the different objectives of both analysises this is not appropriate. A distinction between both limit states, other than just the partial factor would be required. This aspect is indicated in BS 8110 section 3.3 as general guideline, but application in practice is often handicapped by lack of data.
- Monitoring structural performance especially the SLS aspects and evaluation / exchange of results would provide an useful calibrating tool. Monitoring in general will lead to a databank which would support a further development of the probabilistic analysis as tool for structural engineers.