THE SERVICEABILITY LIMIT STATE: MATURED DESIGN TOOL OR CALCULATION PROCEDURE TO SATISFY THE CODE?

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Abstract
This paper presents and describes the SLS/ULS design procedures as a process. Differences between the SLS/ULS procedures are identified and discussed to address the issue as to whether the SLS procedures, as applied at present, have a relevant meaning over and above formal obligations. The discussion is supported by examples from the field of Marine Structures.

The findings result in conclusive statements with a proposal, open for discussion, for future actions.

0 Objective

This paper has been prepared to support discussions at the 1997 Henderson Colloquium. The objective of the author is to critically consider the present SLS procedures in a search for added value and relevant meaning of the procedures. The combination of reflection and examples from the author's consultancy experience has been selected to address this issue.

As such it has not been the objective to report results of scientific research.

1 Introduction

The legal frame work for engineering within the context of the construction industry, as in force in The Netherlands, addresses the issues of Safety, Durability, Fitness for Purpose and Impact on the Environment.

Engineers have the obligation to demonstrate compliance with the, rather generally described, requirements related to these issues.

Material related codes have further processed these general requirements into more detailed rules, as such providing engineers the tools to handle this matter. These tools mainly consist of calculating procedures which, for the majority of engineers in practice, hardly show a convincing and transparent link with the functional requirements underlying the Code. In addition to this it is common practice that an extensive set of rules is specifically developed for a project to further detail code requirements and/or to cope with project specific conditions.

Given the fact of worked detailed criteria replacing functional requirements, the question is triggered as to whether our system of rules provides a reliable basis to address the issues engineers should address: Safety, Durability, Fitness for Purpose and Environmental Aspects.

The main division into a set of rules for the SLS and ULS is widely appreciated as appropriate with a general feeling of scepsis where it concerns the SLS criteria and the thereto related consequences.

This is specifically applicable for the type of structures which carry a more unique character either by their characteristics or by the relative small repetition of concepts such as offshore, marine and harbour structures, specific bridges, submerged tunnels, etc.

A reflection and discussion on SLS aspects is as such appropriate.

2 The Serviceability / Ultimate Limit State: Basic Process

The basic flow scheme of both the SLS and ULS engineering process is presented in Figure 1 and 2. From a global comparison it appears that, in terms of process, the SLS and ULS are approached in the same way.

As certain requirements can only be addressed through a SLS analysis and others only through an ULS analysis, one might come to the quick conclusion that our framework is complete and that both the SLS and ULS analysis have a relevant meaning and contribution and supports the engineer in his efforts to demonstrate compliance with specific requirements.

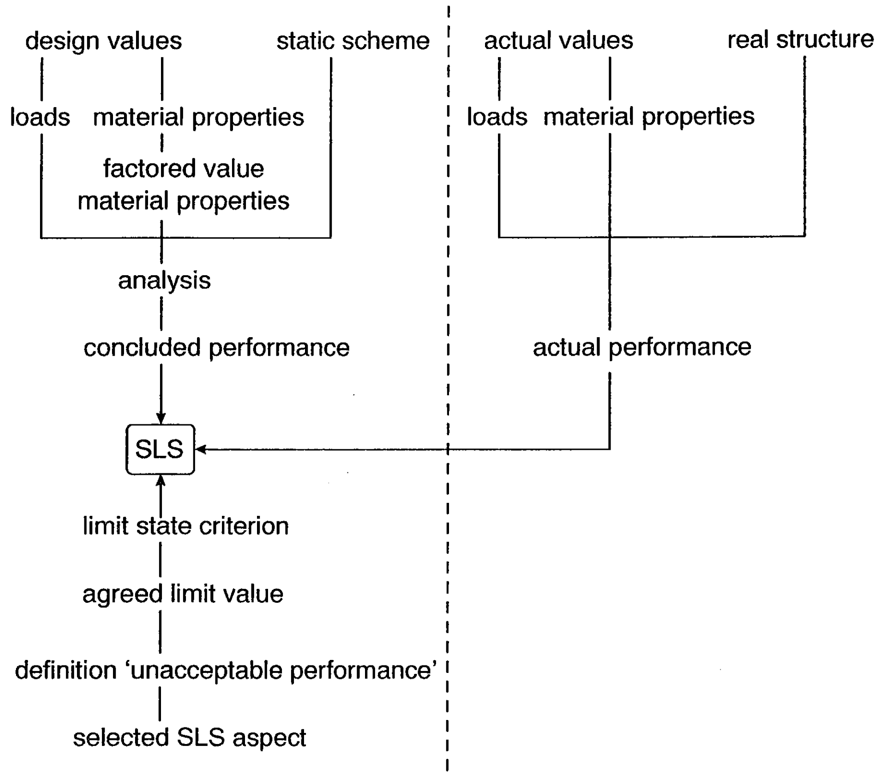

Fig. 1. Flow scheme SLS

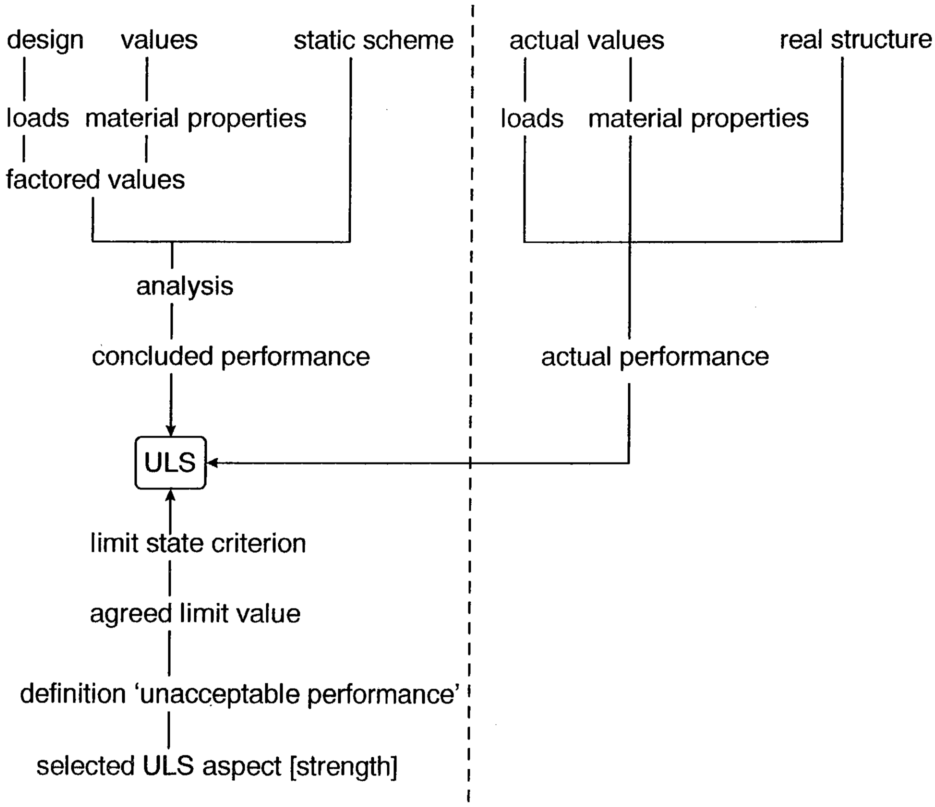

Fig. 2. Flow scheme ULS

This is, as said before, not commonly experienced. To analyse the reason why, both flow schemes are presented again in Figures 3 and 4, but now positions and relations between positions, which in themselves contain uncertainties, have been indicated. These will be further described and discussed in the next section. If now the comparison is made again, it becomes obvious that, although the processes in a descriptive way are comparable, the reliability of at least some of the SLS analysis exercises, is doubtful if considered as an assessment to verify the structure's fitness for purpose.

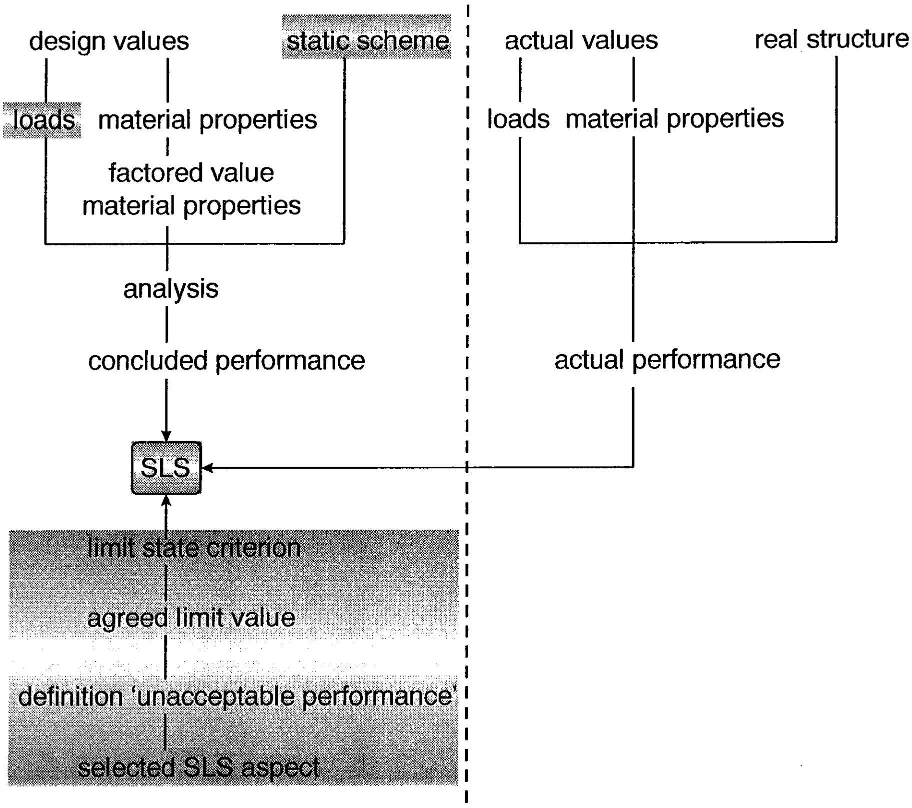

Fig. 3. Uncertainties SLS

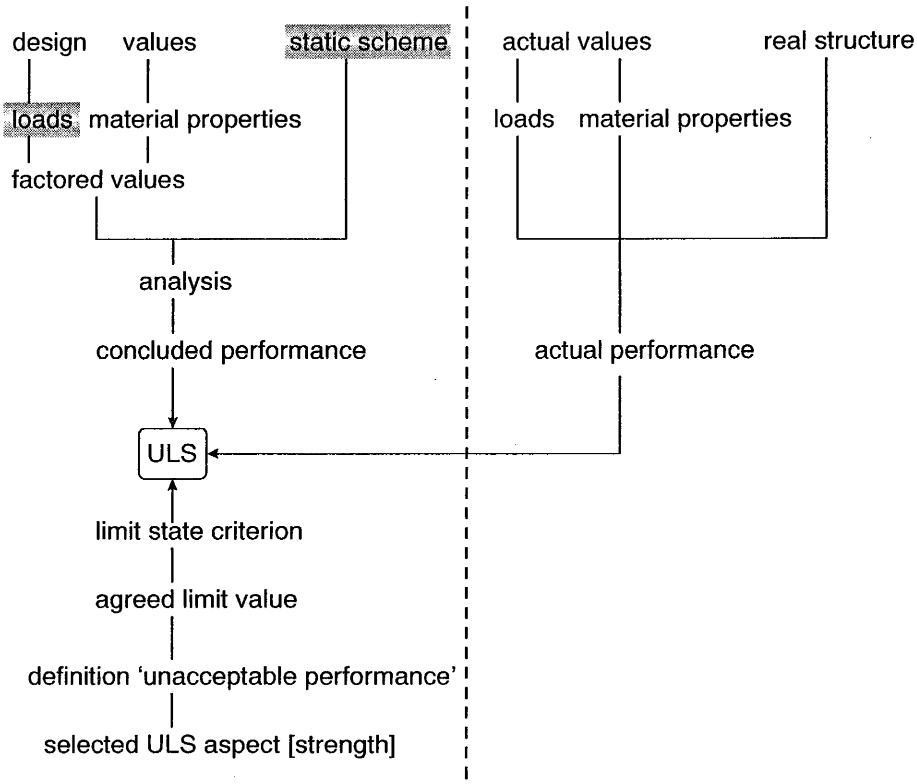

Fig. 4. Uncertainties ULS

It is precisely this aspect, that makes the difference in how uncertainties, beside the extent of uncertainties, work out:

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.

3 Uncertainties of the SLS analysis

1. *Loads*: The actual loads on the majority of structures are rather uncertain. Design loads may be fit for purpose to carry out an analysis, but their representative value in an attempt to analyse the actual response of a structure is limited. Design loads tend to be an overestimation of the actual loads; so is the anticipated response. If compliance with criteria is demonstrated, actual response of the structure will normally be well within the set limits. Given usual upper limit approaches this phenomenon might be considered as satisfactory. It becomes doubtful if such an SLS check appears to be the governing case. In marine structures famous examples of this kind are:

- *Blanket uniform distributed loadings*
  - catwalks, structures connecting the loading platform with surrounding dolphins to give access for the mooring gang, are normally governed by the deflection criteria applicable for a fully loaded structure. A highly hypothetical case to check the SLS!
  - retaining structures: the surcharge behind these structures as well as the waterhead over the retaining wall, is highly uncertain. Despite this uncertainty very strict deformation criteria, often governing, apply.
- *Wave and current loads*

  This is the domain of probabilities. Often these probabilistic aspects are worked out into deterministic tools for engineers.

  Assessment of loadings to take into account for the SLS analysis remains difficult as a specific return period is not defined and subject to discussion all the time. The usual distinction into operational and extreme loadings does not contribute clear definitions.

2. *Static scheme*: As long as the connection to earth of the considered structure is represented as a fixed, rigid support, static schemes are in general reliable. Problems start as soon as the soil-structure interaction, especially related to transversal load transfer, comes into the picture.

   Even a sophisticated scheme whereby a horizontally loaded pile is supported by a large number of multi-linear, elastic-plastic springs does not reflect the coherence of the soil. One would need 3-dimensional finite element models for soil, which is beyond the present state-of-the-art.

3. *Concluded performance*: From the discussion mentioned above it may be clear that the concluded performance as part of the SLS analysis is not necessarily transparent with the actual performance of structures.

   From the examples given [retaining walls, dolphins, catwalks, structures subjected to currents, wind and waves] it may be clear that the concluded discrepancy applies to a larger group of structures.
4. *Selected aspects*: The choice of aspects, to be processed to demonstrate the concept to comply with functional requirements, is more complicated than it superficially appears to be.

   Common aspects are deflection, rotation and crack width.

- *Deflections*

  Deflections normally are the governing case in the design of catwalks and approach trestles. Usual values such as span/600 for total loading apply. Precambers and smart specifications [deflection being the deformation relative to a straight line through supports] have been invented in an attempt to keep other aspects governing or to reduce the impact.

  But deflections on their own do not mean too much. The underlying aspects of own frequency and discomfort by accelerations have completely disappeared although once were a reason to set these criteria as easy accessible requirements. Given the fact that specifications tend to be kept frozen where concepts [both materials, spans and configuration] show developments, it is doubtful whether original functional requirements are still transparent with the 'worked' specification.

  Also in mooring dolphin design, lateral deflection criteria apply. The structure's acceleration under a quick release of mooring lines should be limited, for the safety of personnel releasing the line. But there is no fixed relation between the deformation criterion in absolute value and the intended limitation of acceleration for the wide variety of parameters normally encountered in the design of dolphins.
- *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.

4 Added value of the SLS analysis

For a wide group of structures the SLS analysis, as performed at present, has limited relevance and significance from an engineering point of view. This is not because of the analysis process itself, but more because of the reliability of input data and the applied criteria, which in many cases are not transparent with the functional requirement they intend to replace. As a consequence the SLS analysis often satisfies contractual aspects only.

A reliable SLS analysis is a <u>must:</u>

- At present there is a need to have adequate criteria to check whether a structure is fit for purpose or not. Not only to avoid unnecessary material demand in cases where the criteria are overconservative, but also to enable the engineer to judge the fitness of his concept.
- The increasing number of performance contracts [partly by increased privatisation, partly by the increased significance of total quality systems such as ISO 9000] requires the engineer to be able to demonstrate compliance with functional requirements more than detailed, usual, specifications.
- The ongoing ability to describe systems from an IT point of view will continue and asks for a civil engineering response. Joint efforts will enable engineers to describe the structure's performance with the objective to test fitness for purpose.
  Appropriate aspects to be checked and criteria above the level at which they presently exist should be further investigated and developed, otherwise the added value would be poor.

5 To conclude

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.