Structure-FMEA

Computer-based Support for Quality Assurance in Structural Design

D6 Modeling

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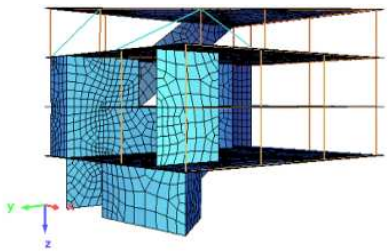

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0 Document History

Version	Date	Changes	Author
1.0	19.11.2010	1st draft	Struss
1.1	19.11.2010	Corrected the glossary, Fig. Fault Classification	Regassa
1.2	19.11.2010	Minor corrections in introduction	Struss
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1 Introduction

This deliverable describes the foundations for a model-based solution to a tool supporting FMEA of structures. Modeling comprises two different perspectives on the structure and its elements:

- the model for computing the load distribution in a structure, given a structural description and type and parameters of the structural elements. This is done based on a standard FE model. For the purpose of FMEA, this computation has to be applied to scenarios that include transformations of the originally designed structure, due to the impact of faults in individual elements and reflected by modified parameters (stiffness) or elimination of elements.

- the model that captures the aspects relevant to FMEA. The core of this model relates to categorizing relevant effects, i.e. essentially a modification of stiffness that is significant considering the function of an element (including the collapse of an element as an extreme case) and instability of (parts of) the structure, and the faults that may in turn result from these effects.

This document first presents a conceptualization of the task and relevant properties, in terms of definitions and a systematized and formalized representation of the concepts and their relationships (section 2). Section 3 provides details on the central concepts of fault and effect and relates the represented information to the expected outcome of the analysis, the FMEA table. The FE modeling and its use for FMEA is described in section 4.

2 FMEA-related Model

The concepts relevant to FMEA are organized around the elements of a structure. They may be organized in a hirerarchical way. However, the central aspects relevant to the analysis,

faults and effects, are related to the elementary structural elements. At higher levels, only the stability of a (sub)structure matters. The following sections define the relevant concepts and show their relationships in terms of UML diagrams.

2.1 Concepts

CriticalEffectElement	A StructuralElement for whom the impact of a fault has to be determined.
CriticalFaultElement	A StructuralElement the influence of whose failing has to be analyzed, thus is the subject of FMEA.
Effect	A state of a StructuralElement under a certain internal reaction. It is represented as a relation between an interval in the value of a MemberReaction and the structural behaviour – a qualification how the StructuralElement would withstand the loading. The interval is defined between two adjacent thresholds in the member reaction. An Effect object belongs to a particular *EffectDefinition* set, and has ▪ *Interval*, represented by lower and upper bounds of magnitude of the reaction ▪ *EffectTypeID* – Type ID of the EffectType ▪ *FaultTypeID* – Type ID of the FaultType ▪ *StiffnessType* ▪ *StiffnessValue*
EffectDefinition	Set of effects defining states of a structural member under whole range of magnitudes of a MemberReaction. It contains a set of all possible *Effect*s of a particular MemberReaction (*ReactionType)* in a particular *StructuralElement* at a specified *Location*. It contains: ▪ *StructuralElementID* ▪ *ReactionType* ▪ *Location* in the StructuralElement ▪ List of *Effects*
EffectInfo	A description of an effect type
EffectType	Classification of Effects that could result in structural elements. It indicates state of the structural element under the given interval of the magnitude of the member reaction ▪ *TypeId:* an identification string

	▪ *EffectInfo:* a description
Fault	Actual or assumed structural fault (defect?) of a StructuralElement. It represents a major deviation of stiffness of the element and is a cause for the redistribution of loads in the structure. Fault results in a *StructuralElement* and has a ▪ *StructuralElementID* – in case of a generic fault, this can be null ▪ *Location* – can be null ▪ *StiffnessValue* : a real value as a percentage of a reference element stiffness ▪ *StiffnessType*: one of the stiffness types {flexural, normal or shear} indicating the relation of a fault to the reaction type causing it. ▪ *FaultTypeID* - TypeId of the FaultType
FaultInfo	A description of a fault type
FaultType	Classification of faults that are possible in a structure, as shown in Table 1. FaultType has the parameters: ▪ *TypeId*: an identification string ▪ *FaultInfo*: a description of the type; a string ▪ *LocalEffect*: a description of the effect of the fault type on the member itself ▪ *PossibleCause*
Interval	a continuous range of the magnitude of a given MemberReaction type, and has ▪ *Lowerbound:* the lower boundary of the magnitude of the MemberReaction, (real) ▪ *Upperbound:* the upper boundary of the magnitude of the MemberReaction, (real) The bounds designate a boundary of transition between two different Effects caused by the MemberReaction.
Location	A certain geometrical point on the Element (a unique reference w.r.t. local or global coordinate system).
MemberReaction	Force or moment along a selected axis at a Location of interest in the element (i.e internal force, bending moment, torsion or shear). A

	MemberReaction object is associated to a particular *StructuralElement* and refers to a certian *ReactionType* and its magnitude that acts at a specific *Location* in the *StructuralElement*. It can cause an *Effect* at the location. It, thus, has ▪ *StructuralElementID* ▪ *ReactionType* ▪ *Location* in the StructuralElement ▪ *ReferenceValue* – a value (magnitude) of the ReferenceMemberReaction (real) *CurrentValue* – magnitude of the actual MemberReaction (real), i.e. after applying changes from NumericalInfluences.
ReactionType	Type of the internal MemberReaction, i.e. whether it refers to axial force, bending moment or shear, and with respect to the different coordinate axes. It indicates force, respectively, bending moment in the x, y, or z direction. ReactionType can be enumerated as: {axialforce, moment_y, moment_z, shear_y, shear_z, torsion }
Stiffness	represents resistance of a structural member to deformation due to flexure (EI), axial load (EA) or shear (GA). Stiffness has ▪ *StiffnessType* ▪ *value* (absolute / or %age of a reference magnitude)
StiffnessType	enumeration of the possible stiffness types – {axial/normal, flexural_Y, flexural_Z, Torsional or shear}. The literals used here are the same as those of ReactionType
StructuralElement	A single structural element. It is characterized by ▪ *StructuralElementID* a globally uniqueID (**guid**) (string), and optionally: ▪ *name* (string) ▪ *description* (string) ▪ *function* (string) It holds a list of *MemberReaction*s and a list of *EffectDefinition*s. It may also have a *Fault* associated to it.
StructuralElementId	A globally unique identification string assigned to each StructuralElement in the Structure. This shall be used to uniquely identify a given element during data exchange between different

	software modules.
StructureId	A unique identification string assigned to a structural sub-system.
Upperbound/ Lowerbound	An upper, resp. a lower boundary given as an absolute value (of stiffness, force, or moment) representing a limit to a given characterization of a fault or effect of an element.

Section 3 presents more detail and examples of faults and effects.

2.2 Diagrams

The following diagrams capture the relationship between these concepts. Figure 1 shows the basic conceptual class diagram of a StructuralElement and objects related to it. It is then transformed in several steps to provide the basis for concrete data structures used in the implementation (see deliverable D8 “software Description”). In Figure 2, the relationship between MemberReaction and Effect is broken down to be represented by the triple StructuralElementID, Location and ReactionType, as well as the Interval of magnitude of the reaction (type). Likewise, Fault is characterized by StructuralElementID, Location, StiffnessType and StiffnessValue.

In Figure 3, Interval is replaced by the lower and upper bounds of the magnitudes of the reaction, but StructuralElementID, Location and ReactionType are moved into the collection EffectDefinition as being common for all effects in this set. The relation between Effect and Fault (i.e. resultingFault) is replaced at least as far as EffectDefinition is concerned by the constituents StiffnessType, StiffnessValue and FaultType.

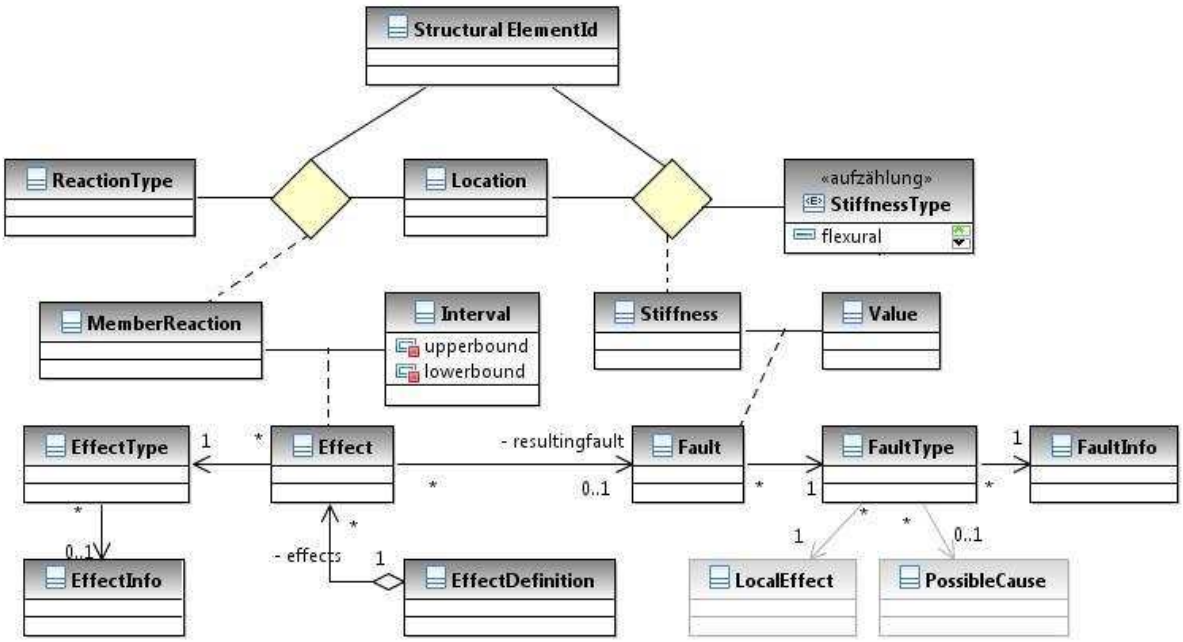


Figure 1: Conceptual class diagram of StructuralElementId and related concepts

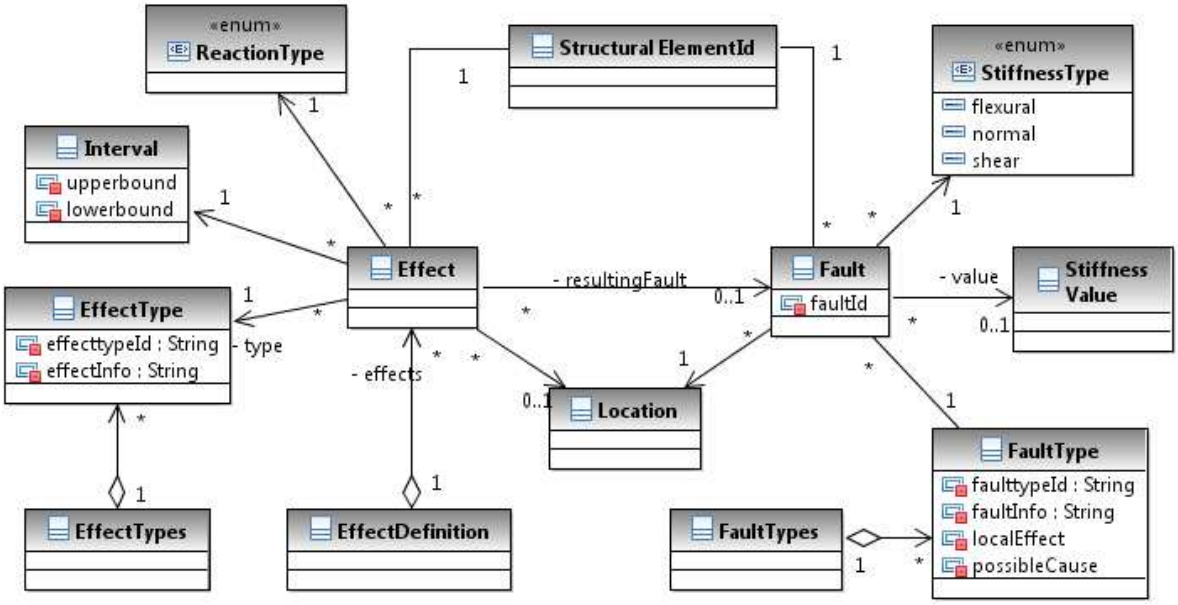


Figure 2: Transformed conceptual class diagram of Effect and Fault

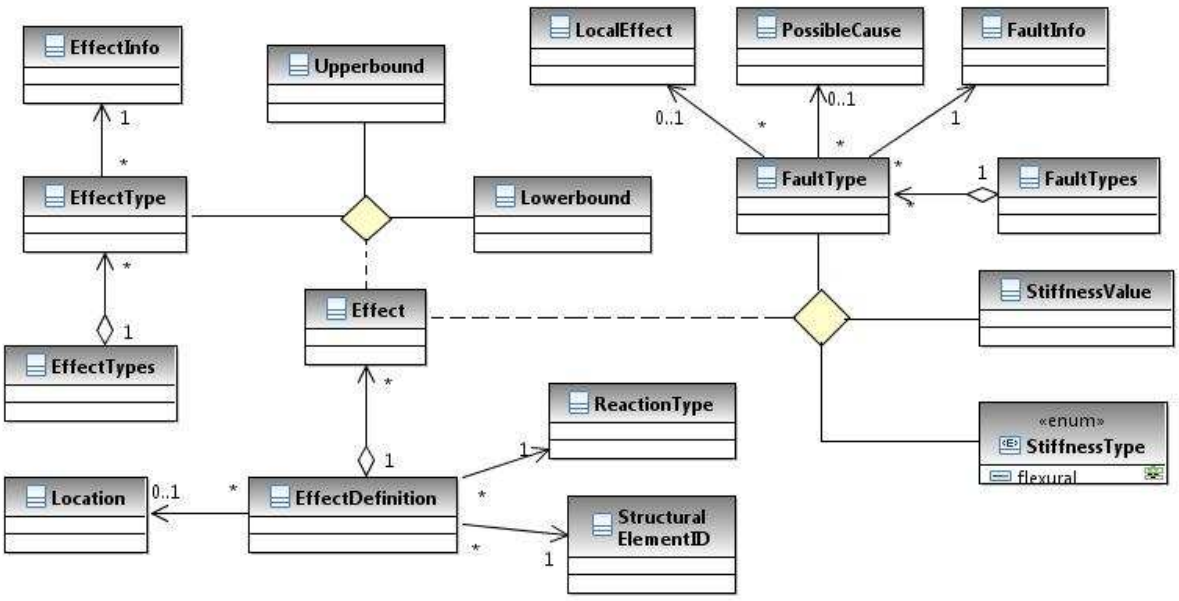
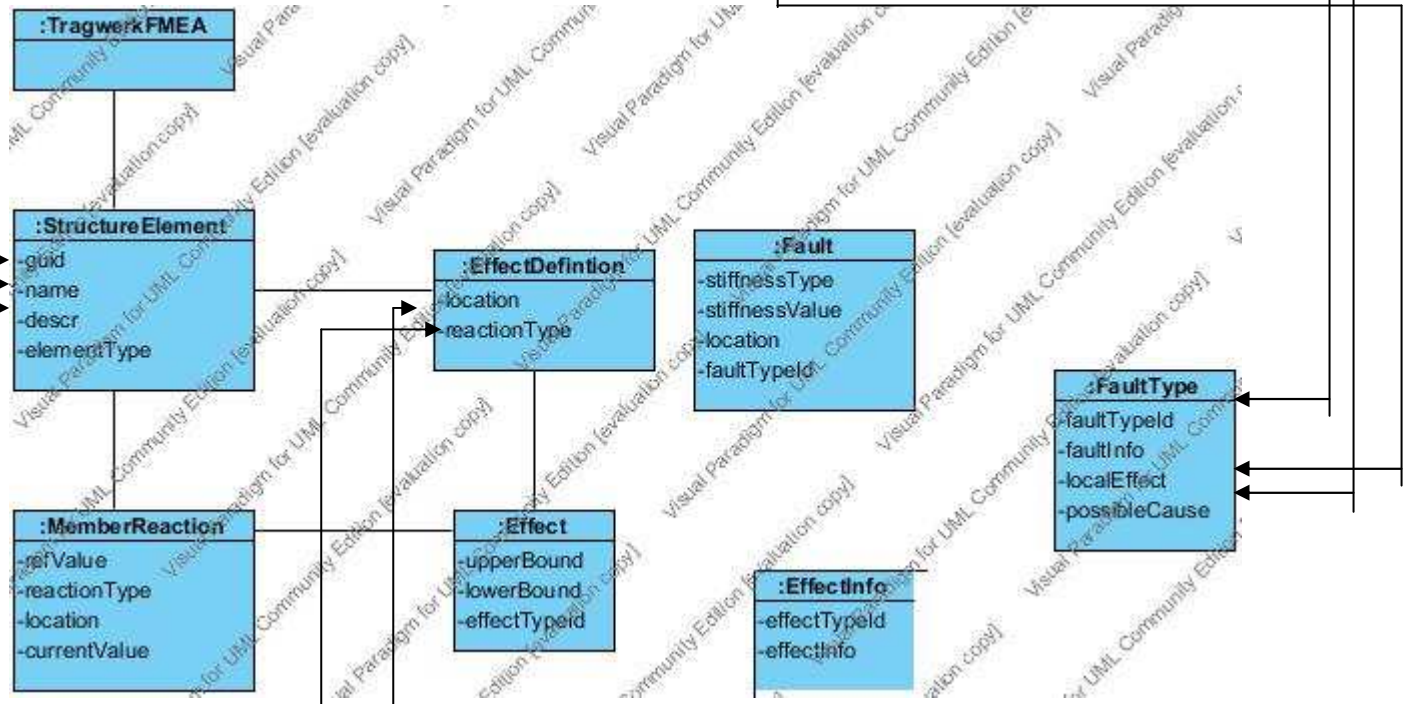


Figure 3: Interrelationship between the conceptual components in EffectDefinition

2.3 Relation to FMEA Table

The following diagram displays the relationship of the introduced concepts to the content of the FMEA Table.

No.	Structural Element				Fault Type and Probability				Consequences of Fault			Detectability		RPN	Control
	GUID	Name	Function	Description	Fault Type (possible)	Possible Cause	A	Remedial Action	Local Effect	System Level Effects	B	Detection Means	E		
int	string	string	string	string	string	string	(int)	string	string	string	(int)	string	(int)	(int)	string



Fault #	Iteration Level	Element ID	Element Name	Reaction Type	Location	Actual value	% change	Effect (local)	Resultant Fault	Comment
(int)	(int)	(string)	(string)	(string)	(string)	(real)	(real)	(string)	(string)	(string)

3 Faults and Effects

3.1 Causes of Fault (Fehlerursachen), Effect types, etc

Causes (design / human error?):

Fehler in Lastermittlung

Lastannahmen zu gering

Fehler in Schnittgrößenermittlung

maßgebende Einwirkungskombination nicht berücksichtigt

Fehler in Bemessung

Fehler in Biegebemessung

Fehler in Schubbemessung

Fehler in Querzugnachweis

Fehler in Stabilitätsbemessung (Kippen)

Fehler in Torsionsbemessung

Fehler in sonstiger Bemessung

keine ausreichende Berücksichtigung der Gefahr des Durchstanzens

Vorgaben aus Zulassung Überschritten – Materialeigenschaften?

Operational Causes:

Material deterioration, section resizing, fatigue, impact/accidents

Consequences

Local:

Einsturz

erhöhte Beanspruchung

Überlastung

sich die Funktion entziehen

eingeschränkte Übertragung der Kräfte

Reduzierte Steifigkeit

System level consequences:

Lastumlagerung,

Veränderung des statischen Systems – räumliche steifigkeit, stabilität

Reduzierte Steifigkeit eines Auflagers

Verlust eines Auflagers

langfristiges Versagen, langfristig Schädigung der restlichen Bauteile

erhöhte Beanspruchung der Bauteile gleicher Ordnung (z.B. benachbarte Stützen)

erhöhte Beanspruchung der Bauteile übergeordneter Ordnung (z.B. Balken, Deckenscheibe)

unbrauchbarkeit der Bau(teile)

Effects Types

Elastic (OK) / plastic range;

Axial/flexural/ shear/ torsional overstressing, punching (direct) shearing;

Buckling (Knick), sway? (Kippen), local buckling (Wolbung), creep (Kriechen), fatigue (Ermüdung);

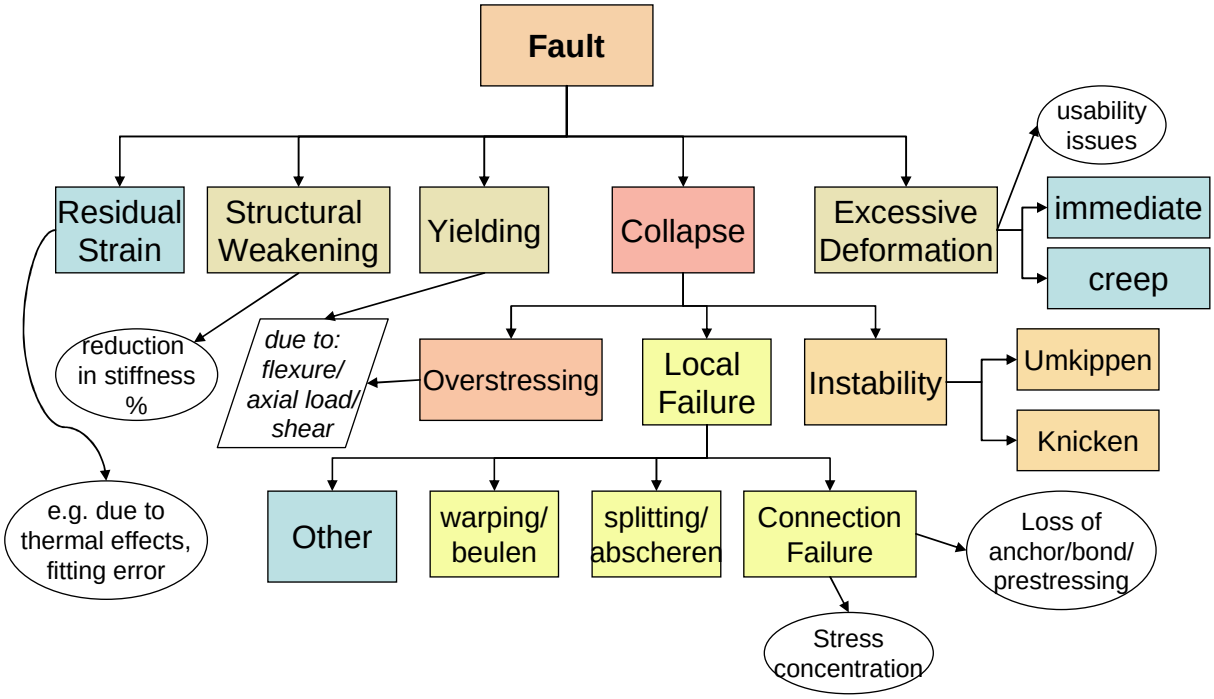
Excessive deformation, foundation subsidence/rotation, excessive crack width, long term deterioration.

Fault Types

Yielding, Failure/collapse, Loss of anchor, loss of prestressing,

Reduction of stiffness (flexural EI, axial (normal) EA, shear GA) – in % ??

3.2 Fault Classification



FaultType is needed as initial fault input into the FMEA process and as a “resultant fault” due to the subsequent load redistribution. Although Fault and FaultType have been extensively discussed in the specifications, no general definition and valid classification of faults have been suggested. The diagram above shows a suggestion towards possibly exhaustive search for possible fault types. Additions, corrections and/or (counter)-suggestions are vitally needed.

Instability (in which ever form) would eventually lead to collapse of the structural element due to overstressing. A local failure could manifest itself as weakeing or failure of a structural connection, which may lead to reduced load transfer or total disconnection of the element from the rest of the structure.

Excepting “Excessive Deformation”, the top fault types could be used as input initial faults in the FMEA analysis. On the other hand, “Structural Weakening” or “Residual Strain” may not be claimed as “Resultant fault” effected by an increased member reaction.

3.3 Example Tables

1. *ReactionType* – an enumeration that will also be used a *StiffnessType* enum.

ReactionType
AXIAL
FLEXURAL_Y
FLEXURAL_Z
SHEAR_Y
SHEAR_Z
TORSIONAL

2. *EffectType*

EffectTypeID	EffectInfo
OK	Allowable range
DEFORM	Causes unacceptable deformation
BUCKLE	Element will buckle
DRILL	Element may twist
YIELD	Carrying capacity of the element is exhausted
FAIL	Structural element collapses

3. *FaultType (example)*

FaultTypeID[1]	FaultInfo	Local Effect	Possible Cause
NONE	No fault	None	none

[1] See FaultKey (4e)

WEAKENING	Reduction in stiffness of structual element	Reduced carrying capacity of section	Reduced section, mechanical damage or material deterioration
YIELD	Yielding	Element undergoes plastic deformation with little or no increase in load	Load exceeds carrying capacity; Too low a margin of safety
OVERSTRESSING	Overstressing	Fails due to stresses exceeding allowable limits	Loads are more that what the section is designed for
LOCAL_FAILURE	Local failure	Failure due to stress concentration	Holes or other structural discontinuities, Weak connections
BUCKLING	Buckling instability	Failure due to lateral buckling	Too slender a structural element
LATERAL_ INSTABILITY	Drill instability	Rotational instability, warping	Duely unproportional cross-section
RESIDUAL_STRAIN	Residual strain due to thermal gradient	increased internal stresses	Exposure to unequal temperatures on different faces

4. Examples of other objects that are going to be exchanged between the modules

a. *StructuralElement*

StructuralElementID	Name	Description	ObjectType
B1C1	Beam b1c1	Reinforced concrete T-Beam, 1st floor	Beam

b. MemberReaction

StructuralElementID	ReactionType	Location	ReferenceValue	CurrentValue
B1C1	FLEXURAL_Y	Mid-point	250.0	215.0

a. EffectDefinition

StructuralElementID: B1C1

ReactionType: FLEXURAL_Y

Location: Mid-point

Effects:

Lower bound	Upper bound	StiffnessType	EffectTypeId	FaultKey
-inf	-100.0	FLEXURAL_Y	FAIL	OVERSTRESSING
-100.0	300.0		OK	NONE

300.0	310.0		YIELD	YIELD
300.0	+inf		FAIL	OVERSTRESSING

b. Fault

StructuralElementID	Location	FaultKey	StiffnessType	StiffnessValue
B1C1	Midpoint	NONE	*	*
		WEAKENING	(type)	(value)
		YIELD	(type)	*
		OVERSTRESSING	(type)	0.0
		BUCKLING		
		LATERAL_INSTABILITY		
		RESIDUAL_STRAIN	(type)	(strain value)
		LOCAL_FAILURE		

e. FaultKey

NONE
WEAKENING
YIELD
BUCKLING
OVERSTRESSING
LATERAL_INSTABILITY
LOCAL_FAILURE
RESIDUAL_STRAIN

4 FE Model

< To be done by Kassel>