RhinoRstab

Introducing and Testing a New Structural Analysis Plugin for Grasshopper3D

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Abstract. This paper presents a new open-source structural analysis plugin for Grasshopper – RhinoRstab. The plugin bridges data between the worldwide established software: Rhinoceros3d and Dlubal RSTAB. The basic idea behind the approach is to create an interactive workflow between the architectural design on the one hand and a structural analysis tool on the other hand. In contrast to RhinoRstab, other analysis tools for Grasshopper predict the structural behaviour independent of its structural capacity. Thus, additional standalone software is necessary to verify the analysis of these plugins subsequently. To test the validity of this new tool, it is compared to a similar application, namely Karamba (a widely used structural analysis plugin for Rhinoceros/Grasshopper). Both tools are tested in different scenarios. The study shows that for some elements in a structural system and some calculation methods RhinoRstab and Karamba results differ strongly. However, regarding the runtime, Karamba operates faster than RhinoRstab.

Keywords: Automation, Structural Analysis, Structural Design, Optimization

1 Introduction

With parametric design gaining currency among structural engineers, information exchange between architectural designs and structural analysis software receives major interest as a design tool [1]. This paper presents a plugin for the workflow of a dynamic inter-process communication between the architectural design and structural analysis software. It combines already existing software and uses their advantages as reliable design and structural calculation tools. The plugin RhinoRstab connects the 3D graphical software Rhinoceros/Grasshopper [2] and the structural analysis program RSTAB by Dlubal [3].
With regards to similar and already existing applications, the Rhino [4] and Rhinoceros/Grasshopper communities offer different solutions for structural analysis. These plugins are able to be executed during the design process, providing a deeper understanding of the structural performance influenced by alterations of the

Erratum

The scientific paper ”RhinoRstab - Introducing and Testing a New Structural Analysis Plugin for Grasshopper3D” contains the assertion that ”. . . for some elements in a structural system and some calculation methods RhinoRstab and Karamba results differ strongly.”. In order to prove their case, the authors compare the results of two structural calculations performed with both programs. **The reported differences in the calculation results are however caused by modelling errors, methodical errors and inaccuracies on the side of the authors of the paper. The corresponding assertions and conclusions in the paper are therefore wrong.**

The paper fails to mention that the pro-student version of Karamba 1.2.2 was compared with RStab version 8.05.0030 (henceforth RStab8 for short). **Also the paper makes wrong assertions regarding the features of Karamba 1.2.2.**

Here a detailed account of the errors contained in the paper:

- In the paper the results of the calculations of structure 1 are wrong because of these modelling errors:
  - In the RStab8 calculation under ”Calculation Parameters” the option ”Activate stiffness factors of materials” was enabled. This makes RStab8 divide the materials Young’s Modulus by the partial safety factor of the material. Since RStab8 uses a partial safety factor of 1.1 for steel, enabling this option increases the calculated displacements by 10% relative to the unfactored case.
  - The structure consists of elements with circular hollow cross sections (CHS) of diameter $57[mm]$ and wall thickness $4[mm]$. In Karamba 1.2.2 the shear areas A_y and A_z are calculated according to the standard textbook formula for a CHS: $A_y = A_z = 2 \cdot A/\pi$ which results in a value of $4.24[cm^2]$. RStab8 uses a value of $3.31[cm]$. This causes deviations in the cross section forces for very short members like those along the upper boundary of structure 1 which have a length of roughly $0.5[m]$.

  Setting the shear areas in Karamba 1.2.2 to those of RStab8 and disabling the stiffness reduction in RStab8, the following differences in the calculation results are observed. The percentages refer the maximum deviation found in all elements to the corresponding mean value of the Karamba and RStab results:

  - Support forces: 0.0001%
  - Maximum normal forces in members: 0.006%
  - Maximum shear forces V_z in members: 0.8%
  - Maximum moments M_y in members: 0.15%
  - Maximum deformation: 0.0003%

The results deviations presented in table 1 on page 132 of the paper are therefore wrong.

- In the paper the results of the calculations of structure 2 are wrong because of these modelling errors:
  - Like for structure 1 a stiffness reduction of 10% was imposed on all materials in the RStab8 calculation.
  - The geometry of the structures calculated with RStab8 and Karamba 1.2.2 was not identical: due to geometric inaccuracies there were two gaps in the Karamba model. In the RStab-model these were not present because the authors of the paper used different tolerance settings in Karamba and RStab for joining neighboring nodes.
  - The comparison of the results from second order theory between RStab8 and Karamba 1.2.2 neglects a difference in the way both programs take account of the normal force N^{II} which causes the second order effects: according to the RStab8 manual RStab8 uses the mean value of the normal forces in a beam as N^{II} whereas Karamba 1.2.2 uses the minimum normal force. This is documented in the Karamba 1.2.2 manual. The latter procedure gives results which lie on the safe side.

    In order to make a valid comparison between second order results of Karamba 1.2.2 and RStab8 one has to divide the beam elements of the structure into small segments so that the difference between N^{II} as calculated in RStab8 and Karamba 1.2.2 becomes negligible. In case of elements where the cross section forces change sign, and the gradient of the cross section force is small, the method of comparing the difference of the results to the corresponding mean value becomes meaningless for judging the correctness of the structural analysis: Tiny variations in the results then cause large relative deviations. Therefore the method for comparing the results of RStab8 and Karamba 1.2.2 by calculating relative deviations is invalid and has a pronounced influence in case of second order structural calculations when small beam segments are used.

Setting the shear areas in Karamba 1.2.2 to those used in RStab8, disabling the stiffness reduction in RStab8 and using the geometry with the gaps for RStab8 and Karamba 1.2.2 the following differences in the calculation results are observed. The percentages refer the maximum deviation found in all elements to the corresponding mean value of the Karamba and RStab results:

- Th.I, support forces: 0.0002%
- Th.I, maximum normal forces in members: 2.7%
- Th.I, maximum shear force V_z in members: 0.02%
- Th.I, maximum moments M_y in members: 0.04%
- Th.I, maximum deformation: 0.3%

  - Th.II, support forces: 3.9%
  - Th.II, maximum deformation: 2.4%

  If each beam is divided into 20 segments the following relative deviations result for the calculation according to second order theory:

  - Th.II, support forces: 0.19%
  - Th.II, maximum deformation: 0.14%

  The results deviations presented in table 2 on page 133 of the paper are therefore wrong.

- On page 129, first paragraph, it is stated that Karamba 1.2.2 creates only stress resultants. This is not the case. Besides stresses and other properties resultant cross section forces, local cross section forces, displacements can be retrieved from beam elements.

- On page 130, section 2.2, first paragraph, it is stated that in Karamba 1.2.2 the selection of predefined cross sections is limited to a smaller range than in RStab8. This is not the case. In version 1.2.2 the cross section library of Karamba comprises roughly 6600 different cross sections. The cross section library can be easily extended by the users and has therefore no limit on the potential number of predefined cross sections.

- On page 131, section 2.2, first paragraph, it is stated that "...Karamba is not proven by any construction standards".

  - In case the authors mean that Karamba 1.2.2 does not contain procedures for designing structural elements according to building codes then this is not correct: Karamba 1.2.2 contains assessment and optimization tools based on Eurocode 3 for steel structures.
  - In case the authors mean that the results of Karamba 1.2.2 are not verified then this is not correct: Karamba 1.2.2 comes with a selection of widely used benchmark examples with comparisons to results known from literature.

- In section 3.3 of the paper the authors draw several comparisons between the results of Rstab8 and Karamba 1.2.2. These comparisons are wrong.

- In section 4.1, first paragraph, it is stated that "...Karamba, in turn, only shows structural behavior but does not demonstrate its actual structural capability". This is wrong: Karamba features assessment and optimization tools based on Eurocode 3 for steel structures. It also lets the user retrieve (besides other result properties) cross section forces and moments for beams and principal stresses and Van Mises stresses for shells.

- In the same paragraph it is stated that "...Karamba also lacks of options to superimposition results.". It is not mentioned in the paper that Karamba 1.2.2 offers the option of load superimposition.

- In the same paragraph it is stated – with respect to the results of Rstab8 and Karamba 1.2.2 – that ". . . it can be observed that the result of the single elements show great differences (up to 71% in structure 1 and 74% in structure 2)". This is wrong.

- In the same paragraph it is stated – with reference to Karamba 1.2.2 – that ". . . as it only shows one result per element, it is not clear where the result force is acting on the element and if it represents the maximum value.". This is wrong. In case of beams Karamba 1.2.2 lets the user retrieve a user defined number of results (displacements, cross section forces,. . .) on equidistant points of the beam axis.

- In the same paragraph it is stated – with reference to Karamba 1.2.2 – that ". . . It also does not distinguish between strong and weak axis of a cross section, and therefore only provides the resultant for both axis.". This is wrong. Karamba 1.2.2 distinguishes between the strong and weak axis of a cross section and provides not only resultants of the cross section forces but also their components in the local element coordinate system.

- **For the reasons described above, the result comparisons in table 1 and table 2 for tree structure 2 in appendix 2 on page 136 for the components of the support forces are wrong.**

parametric design. This structural observation has relevance, especially for complex structures such as the ones created by parametric modelling approaches. During the conceptual design phase this observation is useful for a behavioural estimation and optimisation of structural elements. Besides RhinoRstab one of the most popular parametric plugins is Karamba, which strength lies within the usage in an early design stage [5]. Since this tool creates only stress resultants, accurate structural calculations are required to verify the results subsequently. In this further step the structure is determined according to Building Codes, such as DIN, Eurocode, International Building Code, etc. Different researches show that additional, standalone structural analysis software is used to verify the results of Karamba [6]. Furthermore in the later design stages of projects with higher degree of complexity the usage of certificated program in structural performing is required [1].
A direct connection between Grasshopper and a verified structural analysis software such as RSTAB would therefore eliminate the needs to verify the results in another standalone program and thus allow a more flexible usage throughout all design stages. As the structural design and the calculation happen within the same software-environment, the possibility of a straightforward structural optimising is no longer limited to the early design stage, but could influence more advanced design phases as well. Linking the two software components would therefore result in more reliable design concepts already in early phases, more flexibility throughout all design stages, as well as a great reduction of time and workload for all project participants. In this paper such a connection is established by a new plugin RhinoRstab. It provides a quantitative benchmark based on a structural analysis of spatial structures and discusses the advantages and disadvantages of the software plugins, RhinoRstab and Karamba.

2 Structural Analysis Tools for Grasshopper

The majority of structural analysis tools for Grasshopper is based on Finite Elements as RhinoRstab, Karamba [5] and Millipede [7]. As well as RhinoRstab, all other calculation tools consist of common Grasshopper utility elements and are fully embedded in its friendly interface. The embedding into Grasshopper allows a direct link between the parametric model, the finite element calculator and also optimisation algorithm.
Derived from the notion to create a benchmark for RhinoRstab the plugin is compared with Karamba, following the basic function: specification of material and cross-section properties, support definition, first and second order analysis, and result visualization methodology. Paragraphs 3 and 4 describe the benchmarking on spatial structures, which showing the detail results.

2.1 RhinoRstab: an Open-Source Plugin

RhinoRstab [8] is an open-source developed plugin connecting *RSTAB* and *Grasshopper3D* through the *RS-COM* interface provided by *Dlubal* [9]. To create an interactive workflow between these programs, the plugin is designed in such a way that the workspace is embedded in the *Grasshopper* environment. Using its convenience of a visual programming language, the whole structural analysis process such as support definition, force application and the actual calculation can be controlled in *Grashopper3D* without switching between programs.
Forming the RhinoRstab-plugin, it is separated in different components. One of the three major members is the export tool, which transfers the parametric model from *Rhinoceros* to *RSTAB* including specifications of the structural members regarding support conditions, material and cross section. Another main component is the analysis tool. Exporting the load definition to *RSTAB*, the tool starts the structural analysis and imports the outputs back to *Rhino*. The result-component provides the choice of visualising different analysis results such as the deformation, internal forces and support reactions. Fig. 1 presents all different plugin components.

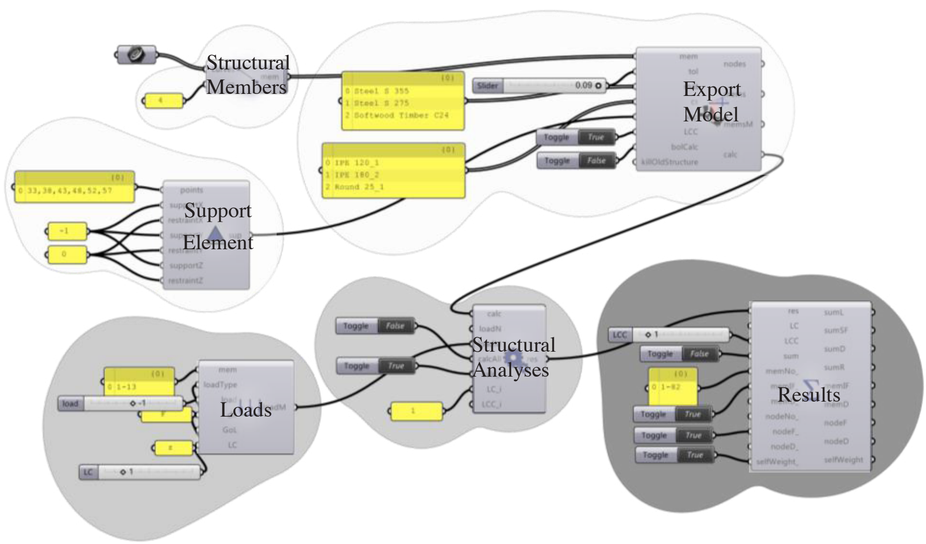

Fig. 1. Illustration of RhinoRstab Plugin Elements

2.2 Comparison to Karamba

Comparing the application of *Karamba* and *RhinoRstab,* both plugins are similar to use. The plugins provide element libraries, including material and cross sections. Where RhinoRstab provides a full selection of international standardized materials and cross-sections, the selection of Karamba is limited to a smaller range.
However, the main difference from *RSTAB* to *Karamba* lies within the calculation, or more precisely in the verification of the results. The significant difference is that the

analysis issued by *Karamba* is not proven by any construction standards. In contrast *RSTAB* enables a user to choose from different international building codes and thus provides a verified proof of stability. *RSTAB* allows a more elaborated and detailed calculation in terms of buckling, 2nd order analyses, dynamic calculation, etc.
Depending on the outcomes of the structural analysis, it may lead to an alteration of the initial design. Thus it is important to provide reliable analysing results in an early design phase. The presented plugin aims at the realization of that goal. Pointing out the difference between the analysis of *Karamba* and *RhinoRstab*, the comparative study shall present an evaluation of the results concerning accuracy and runtime.
In order to provide a detailed comparison of both programs, in the following the plugins are tested in different scenarios such as the structural analysis of structural systems. The parametric models are defined with variable form and cross section parameters following the aim to create an optimized structure.

3 Analysis and Benchmarking of Spatial Structures

In the following two scenarios the analysis of treelike, spatial structures is presented. The design of the first structure (Fig. 2) is kept rather simple in order to prove the authenticity of the results by comparing the software analysis with manual calculations. The second structure demonstrates the usage of both tools analysing a more complex construction. Structure 1 is analysed following theory first order. The theory considers stresses in a simplified manner, analysing the structure as an unformed system. Structure 2 is analysed according to theory first and second order, where theory second order also considers the deformation of the system.

3.1 Analysis of Structure 1

Structure 1 consist of 62 steel rods of different length, from 2.96 to 4.50 meters. Its structural elements are S275 steel profiles, type RO 57x4 | DIN EN 10220_1. Allocating the most convenient position of the trunk, the fixed support is placed in such a way that all moments equal zero. The geometry of structure 1 is shown in Fig. 2.

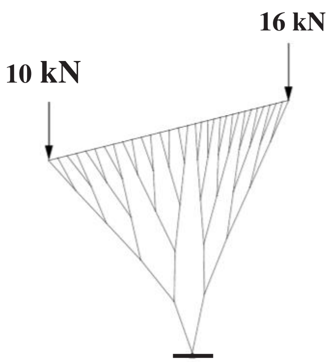

Fig. 2. Tree Structure 1

The first part of the calculation does not take the self-weight into account, in the next step the analysis is repeated also considering the self-weight of the structure.
In Appendix1 the results of the structural analysis are displayed. It shows the support forces of the structure. In addition Table 1 demonstrates the runtime of both plugins and the coefficient of determination R^2, which point out how strongly the results of both calculations correlate. Whereby a R^2 of 1.0 represents identical results and 0.0 indicates no result correlation at all. Furthermore the results of each structural member was analysed and compared. The maximal deviation of each result field was determined regarding the mean value of both programs. In Table 1 the maximal deviation is shown proportional and by its real value.

Table 1. Runtime & Statistical Analysis of Structural Calculations

Software	**Assemble + analysis + results [ms]**	**Total runtime [ms]**		
RhinoRstab	320ms + 675ms + 77ms	1072ms		
Karamba	2ms + 6ms + 56ms	64ms		
Theory		**R^2**	**max result deviation**	
1st order	support-forces	1.000	0.00	0.00
1st order	max. normal-forces in members	1.000	13.2%	0.09kN
1st order	max. shear-forces in members	0.999	58.6%	0.04kN
1st order	max. moments in members	0.986	71.8%	0.03kNm
1st order	max. deformation	0.909	4.8%	78.21mm

3.2 Analysis of Structure 2

The second example shows the structural analysis of a pavilion supported by several treelike pillars (Fig. 3), which consist of 68 rods and 14 beams. The load of the roof gets transferred into the beams, which result in point-loads on the end of each pole (Fig. 3, right). As the whole structure is made of steel S275, the pillars consist of RO 82.5x7.1 | DIN EN 10220_1 profiles.

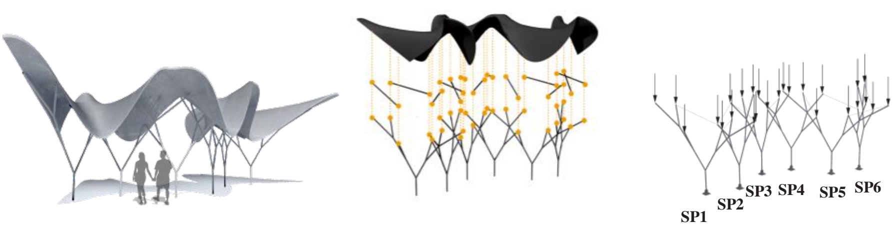

Fig. 3. Perspective of the tree structure 2 (left), exploded view (middle) and structural model (right)

The structure is analysed concerning its internal strain, stresses and support forces, following theory 1st and 2nd order. In Appendix2 the results of RhinoRstab and Karamba are presented , including the self-weight, sum of vertical loads, the total load and its support forces in X, Y, and Z direction. In Table 2 the runtime performance of both programs is demonstrated followed by an estimation of results similarities. Additionally to the coefficient of determination R^2, the single results of Karamba and RhinoRstab were analysed and compared. The max deviation of each result field (i.e. maximal normal forces) is shown proportional and by its actual value. The value was calculated, regarding the mean value of both programs.

Table 2. Runtime & Statistical Analysis of Structural Calculations

Software	**Assemble + analysis + results [ms]**	**Total runtime [ms]**		
RhinoRstab	329ms + 775ms + 112ms	1216ms		
Karamba	83ms + 153ms + 156ms	392ms		
Analysis	**Statistical analysis of**	**R^2**	**max. deviation**	
Th.1st order	support-forces	0.994	52.0%	0.07kN
Th.1st order	max. normal-forces in members	0.992	61.7%	0.032kN
Th.1st order	max. shear-forces in members	0.876	65.8%	-0.70kN
Th.1st order	max. moments in members	0.819	74.0%	0.26kNm
Th.1st order	max. deformation	0.867	6.2%	10.15mm
Th.2nd order	support-forces	0.994	58.5%	0.08kN
Th.2nd order	max. normal-forces in members	0.993	74.1%	0.24kN
Th.2nd order	max. shear-forces in members	0.935	54.3%	0.627kN
Th.2nd order	max. moments in members	0.782	70.0%	2.09kNm
Th.2nd order	max. deformation	0.877	6.5%	14.05mm

3.3 Results

Analysing structure 1 and 2, both programs show in general similar results, as the coefficient values R^2 are mostly around 0.9. The biggest difference for structure 1 lies in the estimation of the maximum deformation with a value of 0.9. Analysing structure 2, the largest difference lies in the results of the second order analysis of moment forces, with 0.782. As the R^2 value evaluates the result in a general way, the individual result values were examined more precisely. This observation shows that despite a high coefficient of determination great deviations exist. The maximum deviation of structure 1 lies in the structural analysis of moment forces with 71.8%. This value is regarding the mean value of both software results. Examining the results of structure 2, the maximum deviation lies in the first order analysis of moment forces

with a value of 74%. In the second order analysis the results of the normal forces show a maximum deviations of 74.0%.
Concerning the runtime of both plugins, Karamba performs the structural analysis quicker than RhinoRstab, 16 times faster in structure 1 and 4 times faster in structure 2.

4 Conclusion and Further Works

In this paper a new structural analysis plugin for Grasshopper is introduced, in which a dynamic inter-process communication between the software Grasshopper and RSTAB is created. Subsequently the RhinoRstab plugin is compared with Karamba, creating a benchmark for the performance of both plugins.

4.1 Conclusion

The functions of RSTAB provide, among other things, dimensioning tools for each building materials and thus is usable for the verification of the results. Karamba, in turn, only shows structural behaviour but does not demonstrate its actual structural capability. Karamba also lacks of options to superposition results, it only offers the choice of either a single or all load cases. This load treatment is rather unfortunate in proper structural analyses, as it presents an important part of the general analysis. Concerning the numerical comparison of the software, it shows that both programs create different results. Though the structural analysis of the plugins provide in general similar results, analysing the results more precisely, it can be observed that the result of the single elements show great differences (up to 71% in structure 1 and 74% in structure 2). A reason for the different results can be that the result output of Karamba is imprecise. As it only shows one result per element, it is not clear where the result force is acting on the element and if it represents the maximum value. It also does not distinguish between strong and weak axis of a cross section, and therefore only provides the resultant for both axis. Comparing both programs the results of RhinoRstab were customised to the result output of Karamba. Another great differences lies in the runtime of both plugins. Karamba performs faster than RhinoRstab and is therefore very suitable for quick alterations, such as performed in optimisation processes. Whereas the strength of Karamba lies within the runtime, the advantage of RhinoRstab is the quality of the analysis. RhinoRstab provides large object libraries and allows very detailed settings concerning structural analysis and result visualizations.

4.2 Further Works

Further works target the improvement of the RhinoRstab plugin for optimisation purposes, finding the most suitable form and cross section for a structure. As optimisation processes usually require a rapid alteration of model properties, the aim

is it to optimize the operation time of RhinoRstab, by simplifying extensive calculation processes.
In the current state of the plugin, the type of parametric models is limited to space-frame structures. In order to analyse plates, walls, shells, etc. it is favourable to base the analysing tool on 3 dimensional finite elements. Additional extension of the plugin‘s abilities target on linking it to the finite element calculator Dlubal RFEM [10], following the same strategies as introduced in the interactive workflow between Rhino and RSTAB.

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Appendix 1

Table 1. Analysis of Tree Structure 1

		F_V [kN]	F_H [kN]	M [kNm]	Comment
1.1	Manual calculation	26.00	0.00	0.00	self-weight not considered
1.1	Karamba	26.00	0.00	0.00	self-weight not considered
1.1	RhinoRstab	26.00	0.00	0.00	self-weight not considered
1.2	Karamba	38.46	0.00	0.00	self-weight considered
1.2	RhinoRstab	38.46	0.00	0.00	self-weight considered

Appendix 2

Table 1. Theory 1st Order Analysis of Tree Structure 2

	Self-weight of structure [kN]		**Sum of vertical point loads [kN]**		**Total load [kN]**	
	Rhino-Rstab	Karamba	Rhino-Rstab	Karamba	Rhino-Rstab	Karamba
	23.228	23.229	48.593	48.593	71.821	71.822
	F_x [kN]		**F_y [kN]**		**F_z [kN]**	
SP1	-0.100	-0.090	0.244	-0.270	22.018	22.670
SP2	0.838	0.930	-0.381	-0.410	8.292	7.860
SP3	0.190	-0.060	-0.200	0.430	5.596	4.260
SP4	-0.272	-0.280	-0.034	0.060	5.604	6.950
SP5	-0.887	-0.620	0.247	0.460	8.2841	8.090
SP6	0.231	0.130	0.124	-0.280	22.026	22.000
Σ	0.000	0.010	0.000	-0.010	71.821	71.830

Table 2. Theory 2nd Order Analysis of Tree Structure 2

	Self-weight of structure [kN]		**Sum of vertical point loads [kN]**		**Total load [kN]**	
	Rhino-Rstab	Karamba	Rhino-Rstab	Karamba	Rhino-Rstab	Karamba
	23.229	23.229	48.593	48.593	71.821	71.822
	F_x [kN]		F_y [kN]		F_z [kN]	
SP1	-0.632	-0.460	0.229	0.060	20.711	21.540
SP2	1.083	1.070	-0.369	-0.580	11.307	10.390
SP3	0.507	0.170	-0.207	0.250	3.892	2.900
SP4	-0.520	-0.620	0.164	0.070	3.890	5.390
SP5	-1.068	-0.810	0.414	0.480	11.303	10.980
SP6	0.629	0.650	-0.230	-0.280	20.719	20.620
Σ	0.000	0.000	0.000	0.000	71.821	71.820