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INTRODUCTION

This verification manual contains numerical examples for structures prepared and originally calculated by Autodesk Robot Structural Analysis Professional version 2012. The comparison of results is still valid for the next Robot versions.
All examples have been taken from handbooks that include benchmark tests covering fundamental types of behavior encountered in structural analysis. Benchmark results (signed as “Handbook”) are recalled, and compared with results of Autodesk Robot Structural Analysis Professional (signed further as “Robot”).

Each example contains the following parts:
- title of the problem
- specification of the problem
- Robot solution to the problem
- outputs with calculation results and calculation notes
- comparison between Robot results and exact solution
VERIFICATION EXAMPLE 1 - DIMENSIONING REINFORCEMENT IN RECTANGULAR SECTION AT BENDING

This example is taken from [1] (in Russian): ПОСОБИЕ ПО ПРОЕКТИРОВАНИЮ БЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ИЗ ТЯЖЕЛОГО БЕТОНА БЕЗ ПРЕДВАРИТЕЛЬНОГО НАПРЯЖЕНИЯ АРМАТУРЫ (к СП 52-101-2003), М., 2005 (example 2)

DESCRIPTION OF THE EXAMPLE:

Calculate the reinforcement in rectangular section at simple bending at ULS. In this example, the results of the program are compared against [1]. One should note that we deal with theoretical (required) areas of reinforcement here. The real (provided) reinforcement is generated by the program in order to fulfill the theoretical reinforcement requirements and structural requirements, and is not analyzed here.

GEOMETRY:

cross section 30х60 [cm]
cover to axis of longitudinal bars a = 4 [cm]

MATERIAL:

concrete B15 (Rb = 8,5 MPa)
reinforcing steel A300 (Rs = 270 MPa)

LOADS:

ing M = 200 [kNm]

IMPORTANT STEPS:

Define the geometry of the beam. The span geometry and the loads should be defined in order to obtain bending moment in the mid-span equal to 200 kNm.

Set proper concrete and steel in Calculation Options, as a on the pictures below. Also create new Element Type.
RESULTS OF CALCULATION:

<table>
<thead>
<tr>
<th>Theoretical areas</th>
<th>[1]</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottom reinf. $A_{s1}$</td>
<td>15,50 cm$^2$</td>
<td>15,36 cm$^2$</td>
</tr>
</tbody>
</table>
VERIFICATION EXAMPLE 2 - DIMENSIONING REINFORCEMENT IN RECTANGULAR SECTION AT BENDING

This example is taken from [1] (in Russian): ПОСОБИЕ ПО ПРОЕКТИРОВАНИЮ БЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ИЗ ТЯЖЕЛОГО БЕТОНА БЕЗ ПРЕДВАРИТЕЛЬНОГО НАПРЯЖЕНИЯ АРМАТУРЫ (к СП 52-101-2003), М., 2005 (example 4)

DESCRIPTION OF THE EXAMPLE:

Calculate the reinforcement in rectangular section at simple bending at ULS. In this example, the results of the program are compared against [1]. One should note that we deal with theoretical (required) areas of reinforcement here. The real (provided) reinforcement is generated by the program in order to fulfill the theoretical reinforcement requirements and structural requirements, and is not analyzed here.

GEOMETRY:

cross section 30x80 [cm]

cover to axis of tension longitudinal bars \( a = 5 \) [cm]

cover to axis of compression longitudinal bars \( a' = 3 \) [cm]

MATERIAL:

concrete B15 (\( R_b = 8.5 \) MPa)

reinforcing steel A400 (\( R_s = R_{sc} = 355 \) MPa)

LOADS:

bending moment \( M = 780 \) [kNm]

IMPORTANT STEPS:

Define the geometry of the beam. The span geometry and the loads should be defined in order to obtain bending moment in the mid-span equal to 780 kNm.

Set proper concrete and steel in Calculation Options, as a on the pictures below. Also create new Element Type.
RESULTS OF CALCULATION:

<table>
<thead>
<tr>
<th>Theoretical areas</th>
<th>[1]</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottom reinf. $A_{s1}$</td>
<td>37.24 cm²</td>
<td>36.2 cm²</td>
</tr>
<tr>
<td>top reinf. $A_{s2}$</td>
<td>8.63 cm²</td>
<td>8.64 cm²</td>
</tr>
</tbody>
</table>
VERIFICATION EXAMPLE 3 - DIMENSIONING REINFORCEMENT IN T SECTION AT BENDING

This example is taken from [1] (in Russian): ПОСОБИЕ ПО ПРОЕКТИРОВАНИЮ БЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ИЗ ТЯЖЕЛОГО БЕТОНА БЕЗ ПРЕДВАРИТЕЛЬНОГО НАПРЯЖЕНИЯ АРМАТУРЫ (к СП 52-101-2003), М., 2005 (example 7)

DESCRIPTION OF THE EXAMPLE:

Calculate the reinforcement in T section at simple bending at ULS. In this example, the results of the program are compared against [1]. One should note that we deal with theoretical (required) areas of reinforcement here. The real (provided) reinforcement is generated by the program in order to fulfill the theoretical reinforcement requirements and structural requirements, and is not analyzed here.

GEOMETRY:

cross section \( b'f = 1500 \text{ mm}, \ h'f = 50 \text{ mm}, \ b = 200 \text{ mm}, \ h = 400 \text{ mm} \)

cover to axis of longitudinal bars \( a = 8 \text{ [cm]} \)

MATERIAL:

concrete B25 (\( R_b = 14.5 \text{ MPa} \))

reinforcing steel A400 (\( R_s = R_{sc} = 355 \text{ MPa} \))

LOADS:

bending moment \( M = 260 \text{ [kNm]} \)

IMPORTANT STEPS:

Define the geometry of the beam. The span geometry and the loads should be defined in order to obtain bending moment in the mid-span equal to 260 kNm.
Set proper concrete and steel in Calculation Options, as on the pictures below. Also create new Element Type.

RESULTS OF CALCULATION:

<table>
<thead>
<tr>
<th></th>
<th>Theoretical areas</th>
<th>[1]</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottom reinf.  $A_{s1}$</td>
<td>24.46 cm$^2$</td>
<td></td>
<td>23.91 cm$^2$</td>
</tr>
</tbody>
</table>
VERIFICATION EXAMPLE 4 - DIMENSIONING REINFORCEMENT IN RECTANGULAR SECTION AT COMPRESSION WITH BENDING

This example is taken from [1] (in Russian): ПОСОБИЕ ПО ПРОЕКТИРОВАНИЮ БЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ИЗ ТЯЖЕЛОГО БЕТОНА БЕЗ ПРЕДВАРИТЕЛЬНОГО НАПРЯЖЕНИЯ АРМАТУРЫ (к СП 52-101-2003), М., 2005 (example 23)

DESCRIPTION OF THE EXAMPLE:

Calculate the reinforcement in rectangular section at compression with bending at ULS. In this example, the results of the program are compared against [1]. One should note that we deal with theoretical (required) areas of reinforcement here.

GEOMETRY:

cross section 40x40 [cm]

height of the column 4,8 [m]

cover to axis of longitudinal bars  a = 5 [cm]

buckling length coefficient k = 1,2

MATERIAL:

concrete B25 (R_b = 14,5 MPa, E_b = 3·10^5 MPa);

reinforcing steel A400 (R_s = R_sc = 355 MPa)

LOADS:

bending moment M = 270 [kNm]

compression force N = 1000 [kN]

IMPORTANT STEPS:

Define the geometry of the column. The value of horizontal load should be defined in order to obtain bending moment in the end of column equal to 270 kNm.
Set proper concrete and steel in Calculation Options, as a on the pictures below. Also create new Element Type.
RESULTS OF CALCULATION:

<table>
<thead>
<tr>
<th>Theoretical areas</th>
<th>1</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{s1} = A_{s2}$</td>
<td>19.18 cm$^2$</td>
<td>19.63 cm$^2$</td>
</tr>
</tbody>
</table>
VERIFICATION EXAMPLE 5 - DIMENSIONING STIRRUPS SPACINGS REINFORCEMENT IN THE CALCULATION OF INCLINED SECTION OF THE ACTION OF SHEAR FORCES

This example is taken from [2] (in Russian): ПРОЕКТИРОВАНИЕ И СТРОИТЕЛЬСТВО В СИБИРИ, №6(36), 2006 (табл.8)

DESCRIPTION OF THE EXAMPLE:

Calculate the shear reinforcement (stirrups spacings) in simply supported beam with rectangular section. In this example, the results of the program are compared against [2].

GEOMETRY:

cross section 20x50 [cm]

cover to axis of longitudinal bars a = a’ = 4 [cm]

MATERIAL:

concrete B20 ($R_{bt} = 0,9$ MPa, $\gamma_{bt}=0,9$)

reinforcing steel A400 ($R_{sw} = 285$ MPa)

LOADS:

shear force $Q = 270$ [kN]

IMPORTANT STEPS:

Define the geometry of the beam. The span geometry and the loads should be defined in order to obtain shear force in the end of the beam equal to 270 kN.

Set proper concrete and steel in Calculation Options, as a on the pictures below. Also create new Element Type.
RESULTS OF CALCULATION:

<table>
<thead>
<tr>
<th>stirrups spacing</th>
<th>[2]</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sw</td>
<td>10 cm</td>
<td>10 cm</td>
</tr>
</tbody>
</table>
VERIFICATION EXAMPLE 6 - CALCULATION OF CRACKING WIDTH IN PANEL

This example is taken from [1] (in Russian): ПОСОБИЕ ПО ПРОЕКТИРОВАНИЮ БЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ИЗ ТЯЖЕЛОГО БЕТОНА БЕЗ ПРЕДВАРИТЕЛЬНОГО НАПРЯЖЕНИЯ АРМАТУРЫ (к СП 52-101-2003), М., 2005 (example 43)

DESCRIPTION OF THE EXAMPLE:

Calculate the cracking width in foundation slab at bending at SLS.

GEOMETRY:

- slab thickness 30 [cm]
- slab dimensions 115 x 400 [cm]

MATERIAL:

- concrete B15 ($R_{bt,ser} = 1.1$ MPa, $R_{ct,ser} = 11$ MPa);
- reinforcing steel A400 ($R_s = R_{s,ser} = 355$ MPa).
Autodesk Robot Structural Analysis Professional - Verification manual for SP 52-101-2003 code

bar diameter $d = 14$ [mm]

cover to axis of longitudinal bars $a = 4.2$ [cm]

Duration factor of loads $= 0.83$ (see below Loads)

**LOADS:**

By the condition of an example, the area of reinforcement and number of bars is: $A_s = 9.23$ [cm$^2$] and 6 $\varnothing 14$. To get this area of reinforcement on the ULS, we create load case DL1 with load $p_z = -39$ [kN/m$^2$].
For the calculation of SLS we create load case DL2 with load $pz = -30 \text{ [kN/m]}^2$. By the condition of an example, bending moment in slab must be $60 \text{ [kNm]}$ (including from long-term loads [kNm] and correspondingly duration factor of loads $50/60 = 0.83$).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>[1]</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement area in the middle of the plate $A_s$</td>
<td>9,23 cm²</td>
<td>9,29 cm²</td>
</tr>
<tr>
<td>Long-term cracking width $a_{erc}$</td>
<td>0,2 mm</td>
<td>0,2 mm</td>
</tr>
</tbody>
</table>
VERIFICATION EXAMPLE 7 - CALCULATION OF PLATE DEFLECTION

This example is taken from [1] (in Russian): ПОСОБИЕ ПО ПРОЕКТИРОВАНИЮ БЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ИЗ ТЯЖЕЛОГО БЕТОНА БЕЗ ПРЕДВАРИТЕЛЬНОГО НАПРЯЖЕНИЯ АРМАТУРЫ (к СП 52–101-2003), М., 2005 (example 45)

DESCRIPTION OF THE EXAMPLE:

Calculate of deflection in the slab at bending at SLS.

GEOMETRY:

slab thickness 20 [cm]

slab dimensions 100 x 560 [cm]

MATERIAL:

concrete B15 ($R_{bt,ser} = 1,1$ MPa, $R_{t,ser} = 11$ MPa)

reinforcing steel A400 ($Rs = Rsc = 355$ MPa)

cover to axis of longitudinal bars $a = 2,7$ [cm]
Duration factor of loads = 0,93 (see below Loads)

LOADS:

By the condition of an example, the area of reinforcement and number of bars is: $A_s = 7,69 \text{ [cm}^2\text{]}$ and 5 $\varnothing 14$. To get this area of reinforcement on the ULS, we create load case DL1 with load $pz = -9,75 \text{ [kN/m}^2\text{]}$. 
For the calculation of SLS we create load case DL2 with load \( p_z = -7 \) [kN/m^2]. By the condition of an example, bending moment in slab must be 6,5 [kNm] (including from long-term loads [kNm] and correspondingly duration factor of loads 6,5/7 = 0,93).
### COMPARISON

<table>
<thead>
<tr>
<th>Parameter</th>
<th>[1]</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement area in the middle of the plate $A_s$</td>
<td>7,69 cm²</td>
<td>7,69 cm²</td>
</tr>
<tr>
<td>Deflection</td>
<td>3,15 cm</td>
<td>3,1 cm</td>
</tr>
</tbody>
</table>

![Image of Autodesk Robot Structural Analysis Professional interface](image-url)
1. ПОСОБИЕ ПО ПРОЕКТИРОВАНИЮ БЕТОННЫХ ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ ИЗ ТЯЖЕЛОГО БЕТОНА БЕЗ ПРЕДВАРИТЕЛЬНОГО НАПРЯЖЕНИЯ АРМАТУРЫ (к СП 52-101-2003), М., 2005
2. ПРОЕКТИРОВАНИЕ И СТРОИТЕЛЬСТВО В СИБИРИ, №6(36), 2006