

# OPTUM GX

Verification of plate element with rigid plastic properties



## Table of content

1	Introduction .....	3
1.1	Plate element.....	3
1.2	Upper, lower and mixed .....	3
1.3	Material models and yield conditions .....	3
2	Square plate with fixed supports – isotropic Nielsen.....	5
3	Hexagonal plate with simple supports. Isotropic Nielsen .....	6
4	Rectangular plate with simple supports. Isotropic Nielsen .....	7

## 1 Introduction

### 1.1 Plate element

OPTUM GX uses a triangular plate (shell) element with a quadratic displacement field. The stress and moment fields are linear and described by a total of 18 variables. The in-plane part of the plate element contributes to 7 nodes, whereas one is a centre node and the remaining 6 are corner nodes and edge (midpoint) nodes. The begin part of the plate element uses the same corner and edge nodes as well as two nodes along each edge for moment continuity.

### 1.2 Upper, lower and mixed

Currently in OPTUM GX the plate element is based on a so-called mixed formulation which in essence is a hybrid, or mixed, formulation of an upper and lower bound formulation. The output results when using the plate element with a mixed formulation is guaranteed to be within the brackets of the upper (unsafe) and lower (safe) bounds. The hybrid formulation ensures an superb precision.

Currently in OPTUM GX the mixed formulation is the only element available.

### 1.3 Material models and yield conditions

Three plate models are available for the yield criterion, namely von Mises, Johansen, and Nielsen. General for all three models is that plate bending and in-plane actions are handled completely separate.

#### Von Mises

The Von Mises model uses a criterion based on the second stress invariant,  $J_2$ , for the in-plane action, and an identical model with the moment variables for the plate bending. In principal stresses (and moments) the yield surface has the shape of an ellipse. In OPTUM GX, the user must supply a yield moment [kNm/m] for the plate bending, and a yield strength [MPa] as well as a thickness [m]. In general, the von Mises model is mostly suited for metals.

#### Johansen

In Johansen model, the first and second principal stresses and moments are independent, and the yield surface takes the shape of a box. For the in-plane action, a compressive strength [MPa], a tensile strength [MPa], and a sectional area [m<sup>2</sup>/m] define the capacity. For plate bending, only a single yield moment [kNm/m] is needed. The Johansen model is suited for reinforced concrete plates with isotropic reinforcement.

#### Nielsen

The Nielsen model expands the Johansen model. For the in-plane action, the model uses a single tensile strength corresponding identical reinforcement in the x and y-directions. For plate bending, a total of four yield moments are required in order to define the yield envelope, namely positive and

negative yield moments in the x and y-directions. The Nielsen model is suited for reinforced concrete plates with anisotropic reinforcement.

## 2 Square plate with fixed supports – isotropic Nielsen

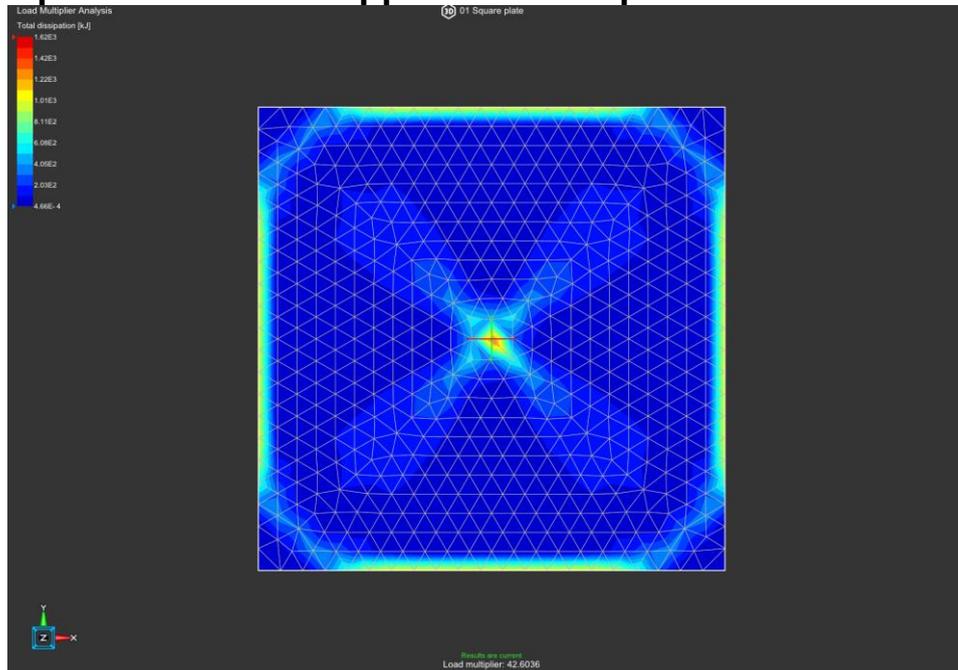


Figure 1: Square plate with fixed supports. Plastic dissipation displaying collapse mechanism

<b>Benchmark</b>	42.851
<b>Results</b>	42.604
<b>Discrepancy</b>	0.58%

### General description:

Square 1x1m isotropic reinforced concrete plate. All edges with fixed supports Loaded with unit area load of 1.0 kPa

### Material properties:

Name	Flat plate (concrete)
Material Model	Nielsen plate
Color	<span style="color: red;">■</span> Change...
Reducible Strength	Yes
<b>Strength</b>	
$m_{px}$ (kNm/m)	1
$m_{py}$ (kNm/m)	1
$f_c$ (MPa)	1
$f_t$ (MPa)	1
<b>Stiffness</b>	
E (MPa)	1
$\nu$	0

### Partial factors:

Unity

### Reference:

M.P. Nielsen, Limit Analysis and Concrete Plasticity, CRC Press (2011), p. 452

### 3 Hexagonal plate with simple supports. Isotropic Nielsen

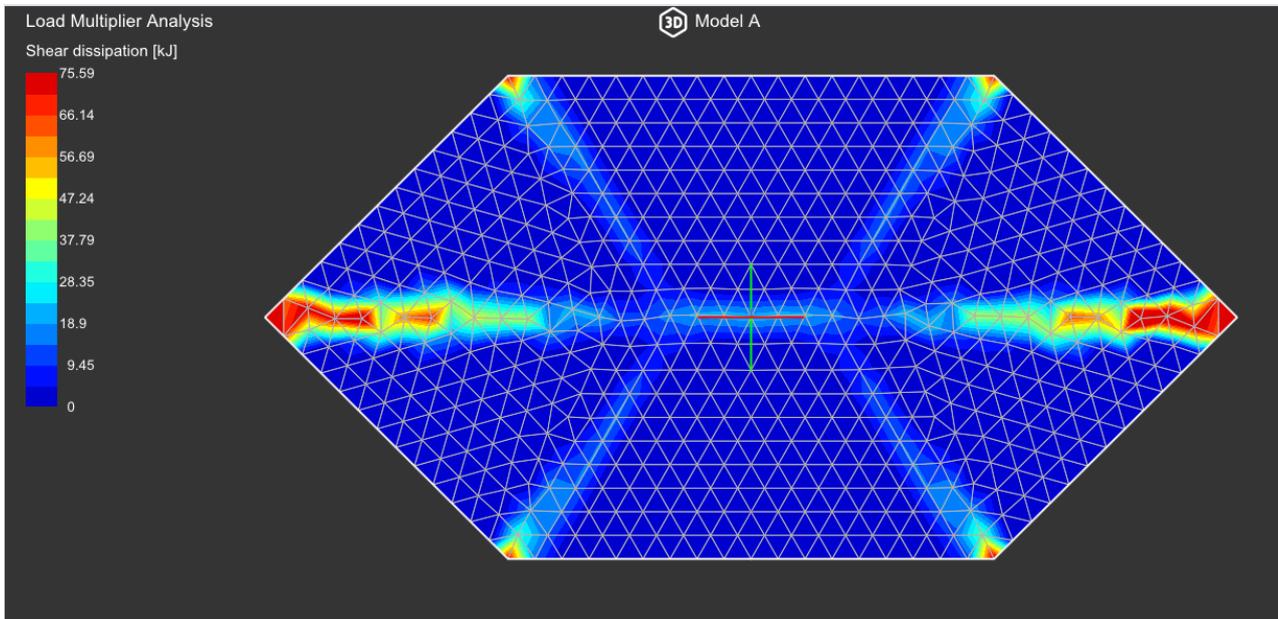


Figure 2: Hexagonal plate with simple supports. Plastic dissipation displaying collapse mechanism.

<b>Benchmark</b>	3.956
<b>Results</b>	3.954
<b>Discrepancy</b>	0.05%

#### General description:

Hexagonal isotropic reinforced concrete plate. All edges with simple supports Loaded with unit area load of 1.0 kPa. Side lengths 2.0 m and 1.4142 m.

#### Material properties:

Name	Flat plate (concrete)
Material Model	Nielsen plate
Color	<span style="color: red;">■</span> Change...
Reducible Strength	Yes ▼
<b>Strength</b>	
$m_{px}$ (kNm/m)	1
$m_{py}$ (kNm/m)	1
$f_c$ (MPa)	1
$f_t$ (MPa)	1
<b>Stiffness</b>	
E (MPa)	1
$\nu$	0

#### Partial factors:

Unity

#### Reference:

M.P. Nielsen, Limit Analysis and Concrete Plasticity, CRC Press (2011), p. 450

## 4 Rectangular plate with simple supports. Isotropic Nielsen

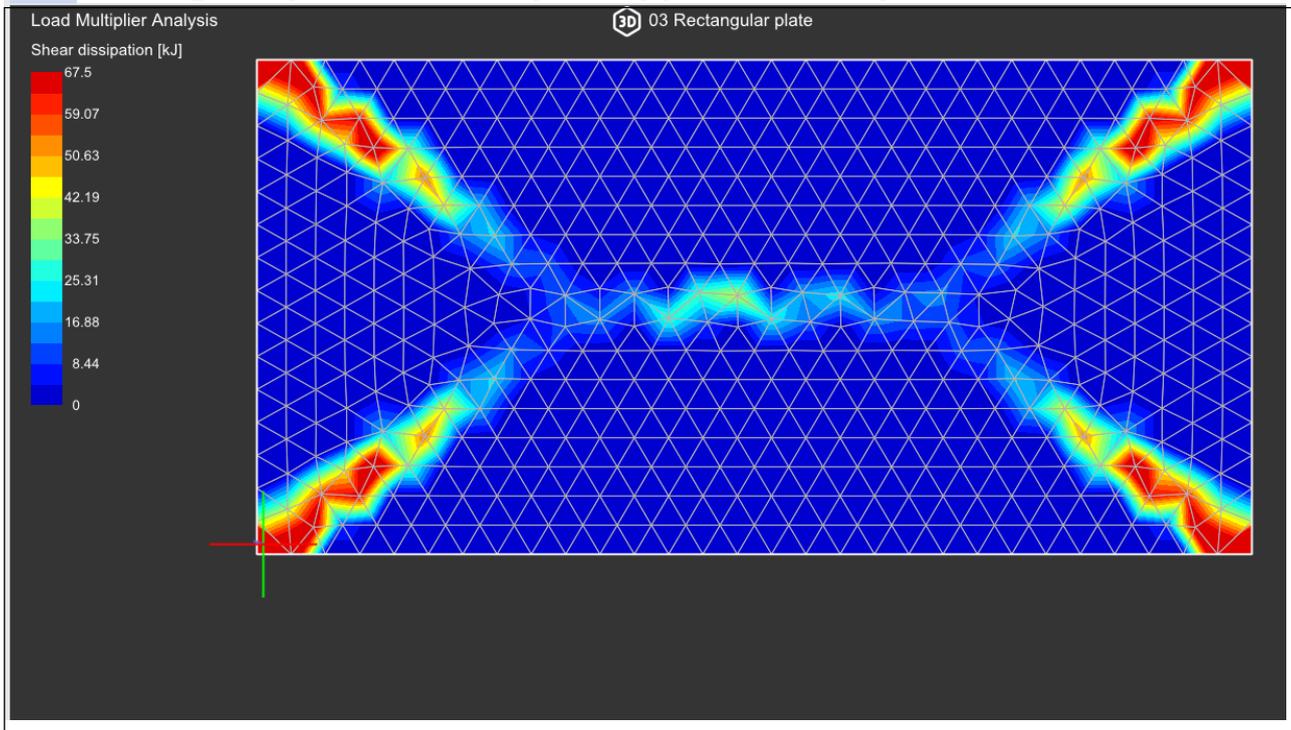


Figure 3: Rectangular plate with simple supports. Plastic dissipation displaying collapse mechanism

<b>Benchmark</b>	3.535
<b>Results</b>	3.526
<b>Discrepancy</b>	0.25%

### General description:

Rectangular 2x4 m isotropic reinforced concrete plate. All edges with simple supports Loaded with unit area load of 1.0 kPa.

### Material properties:

Name	Flat plate (concrete)
Material Model	Nielsen plate
Color	<span style="color: red;">■</span> Change...
Reducible Strength	Yes
<b>Strength</b>	
$m_{px}$ (kNm/m)	1
$m_{py}$ (kNm/m)	1
$f_c$ (MPa)	1
$f_t$ (MPa)	1
<b>Stiffness</b>	
E (MPa)	1
$\nu$	0

### Partial factors:

Unity

### Reference:

M.P. Nielsen, Limit Analysis and Concrete Plasticity, CRC Press (2011), p. 467

