SiF 2022

The 12th International Conference on Structures in Fire

Modelling composite slabs in fire

SiF 2022 workshop: OpenSees for fire, 29 Nov 2022

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Contents

- What is composite slab and why is it difficult to model
- The existing numerical models for composite slabs
- Evolution of composite slab models within OpenSees for fire framework

Contents

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- What is composite slab and why is it difficult to model
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What is composite slab and why is it difficult to model

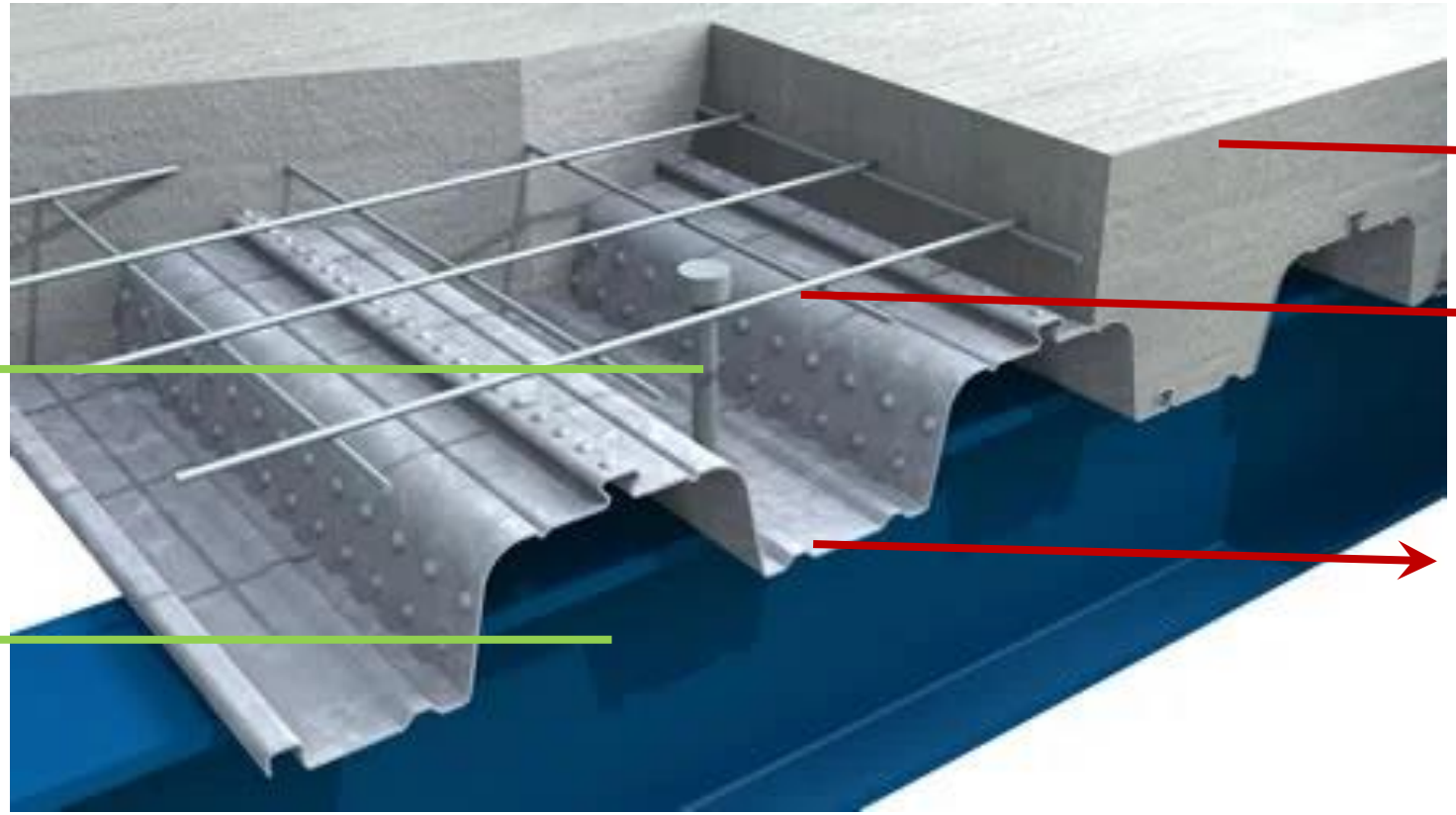
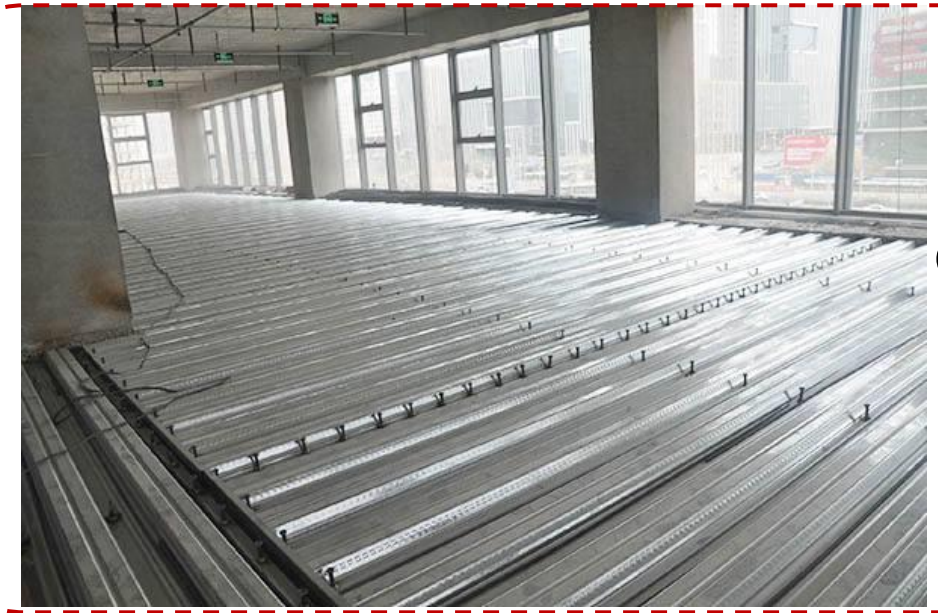


Diagram can be found from https://www.indiamart.com

What is composite slab and why is it difficult to model

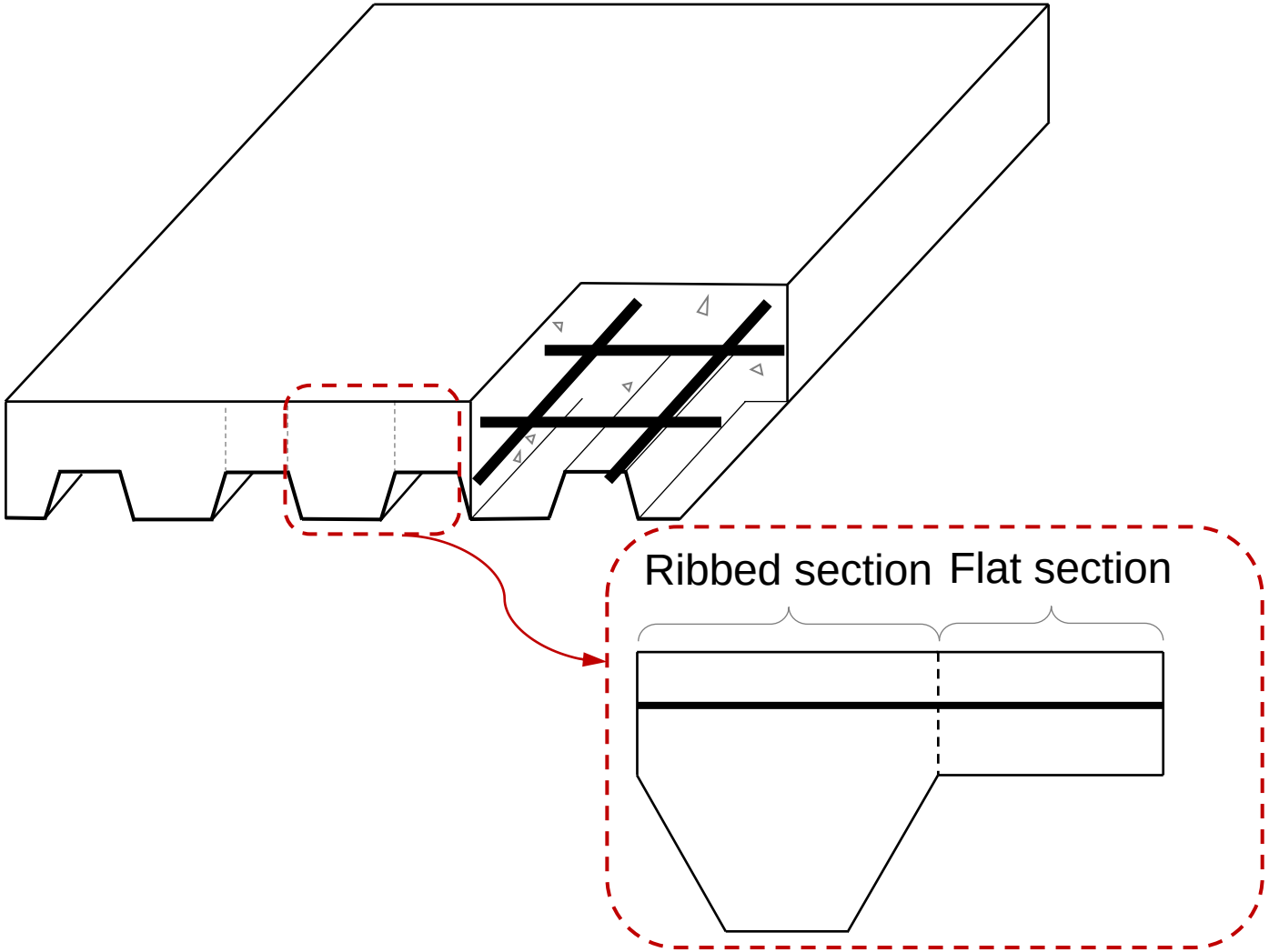
Steel structure workshop



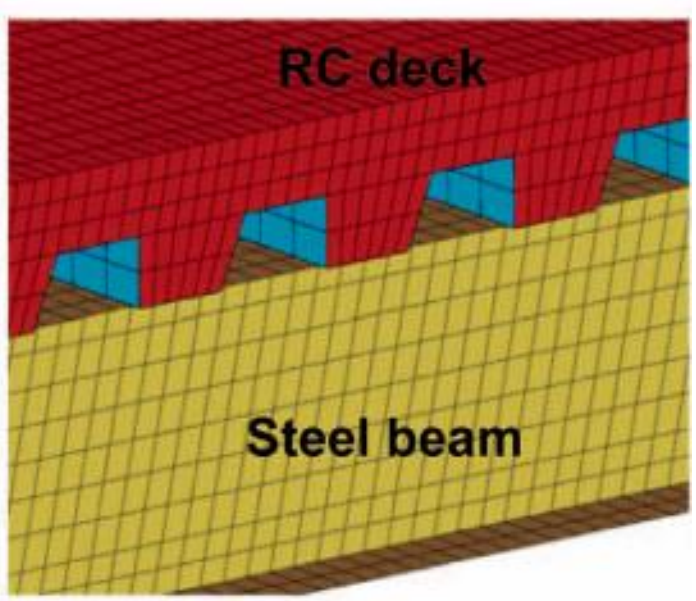
Office building

Infrastructures

What is composite slab and why is it difficult to model



Cross-section with non-uniform thickness



Solid element

The computation cost?

Contents

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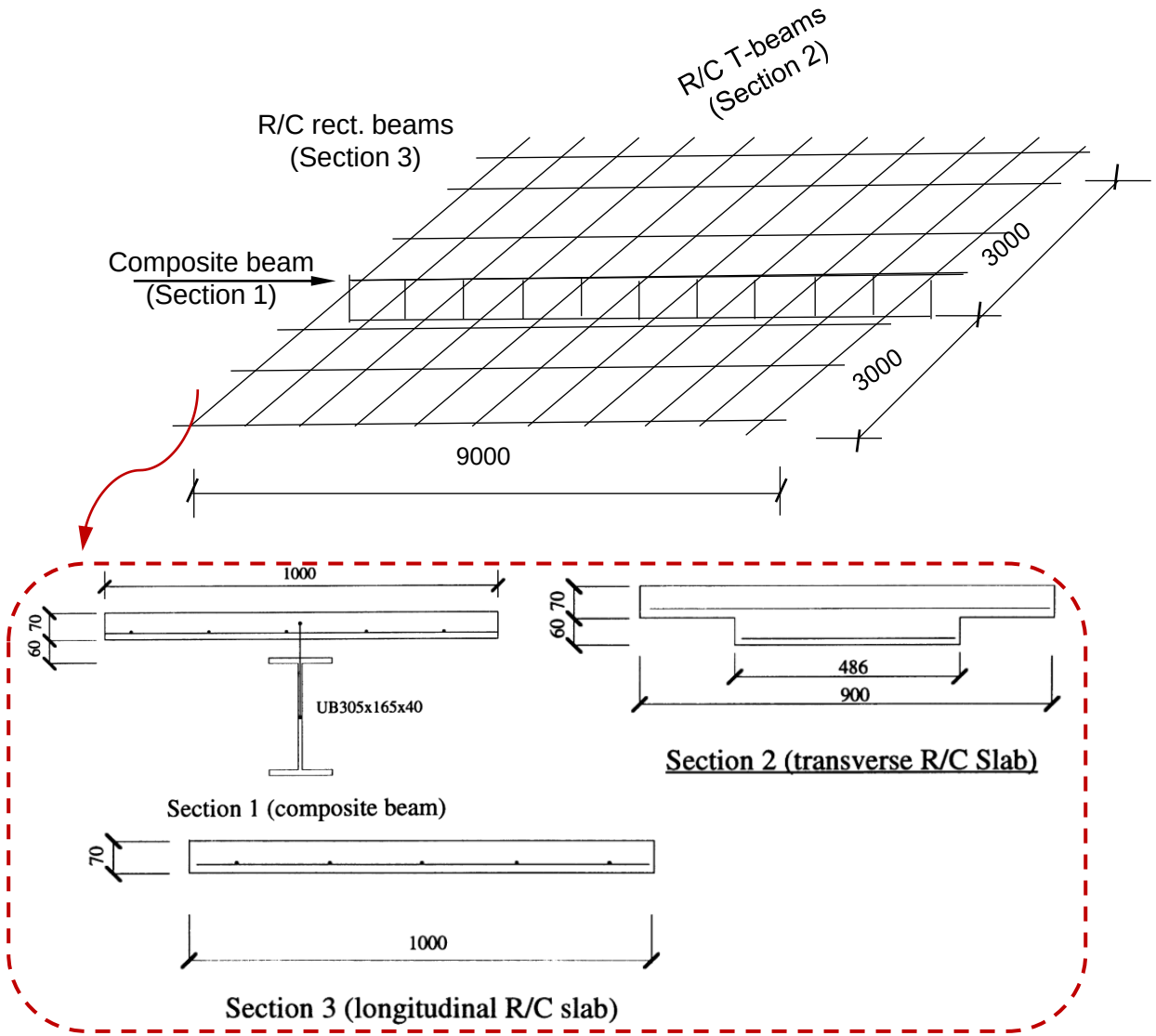
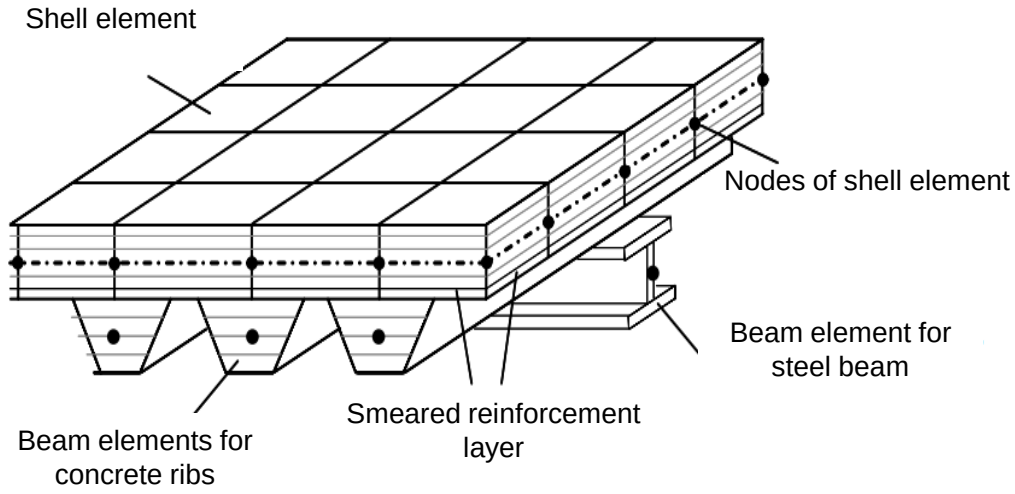
The existing numerical models for composite slabs

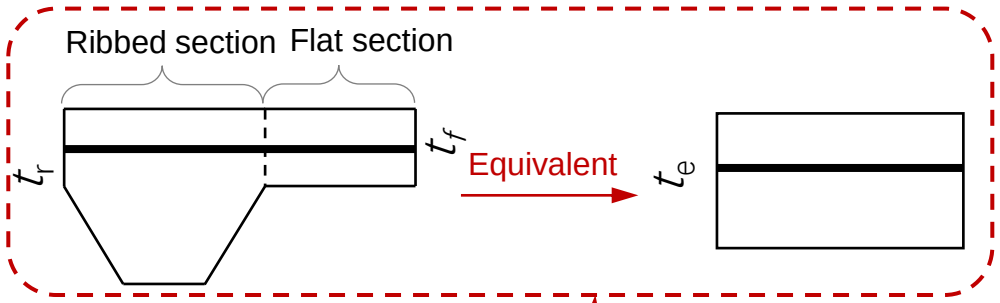


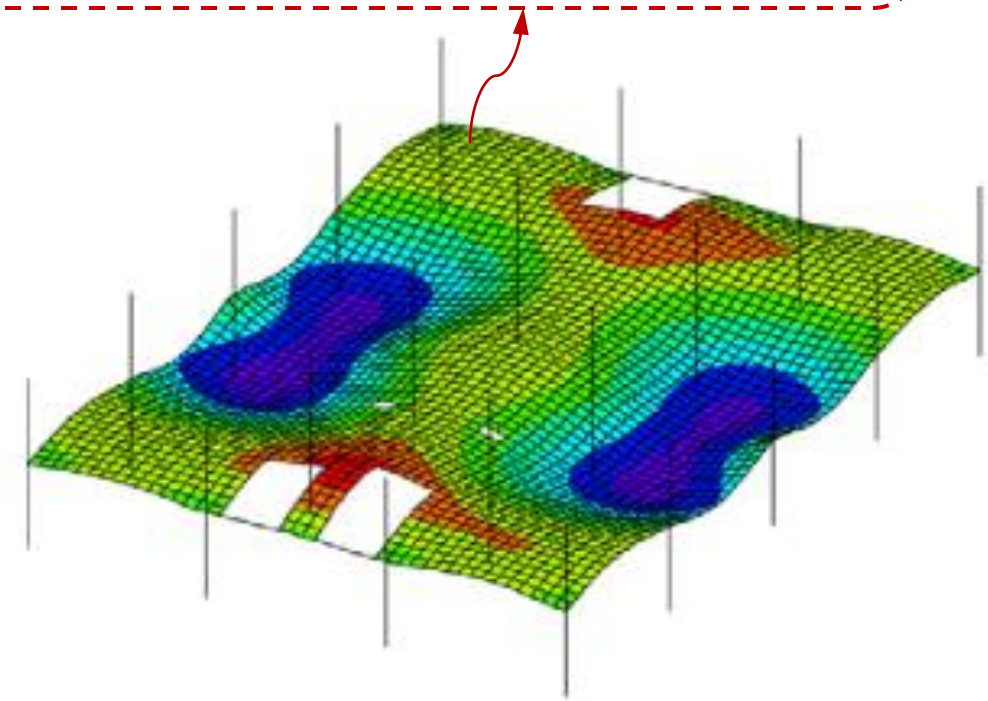
(a) Grillage model
(Elghazouli et al. 2000)



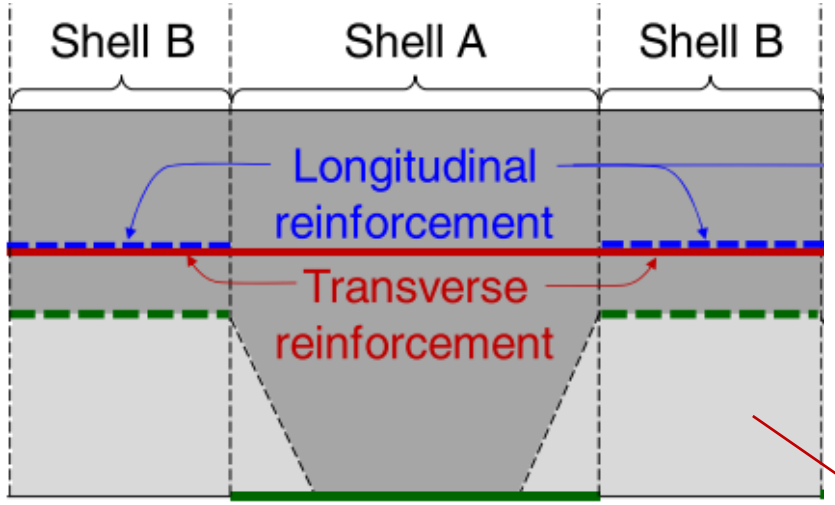
(b) Combination of shell&beam model
Jiang et al. (2014)

The existing numerical models for composite slabs





(c) Equivalent flat slab model



(d) Alternate stripe shell model
(Jiang et al. 2020)

The existing numerical models for composite slabs

How to model the composite slabs with **high computation efficiency**, **accuracy (without compromise)** and **reduced modelling efforts ?**

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- What is composite slab and why is it difficult to model
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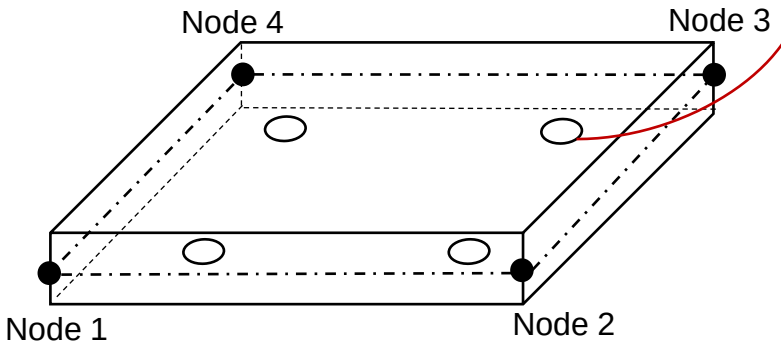
- Evolution of composite slab models within OpenSees for fire framework

Evolution of composite slab models within OpenSees for fire framework

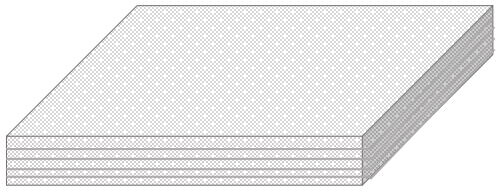
Shell Element

- ShellMITC4Thermal element
  linear elastic
- ShellNLDKGQThermal element
  geometric nonlinearity

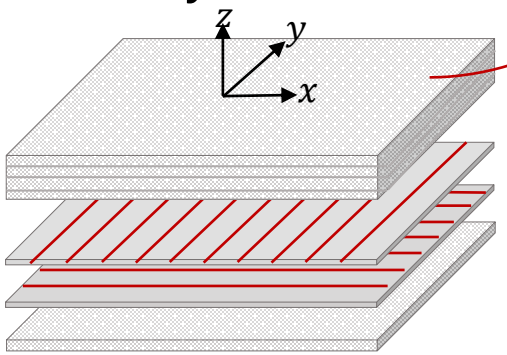


Layered Section

- Membrane section



- Multi-layered section



Material

Steel or concrete:

- ElasticIsotropicThermal

Steel:

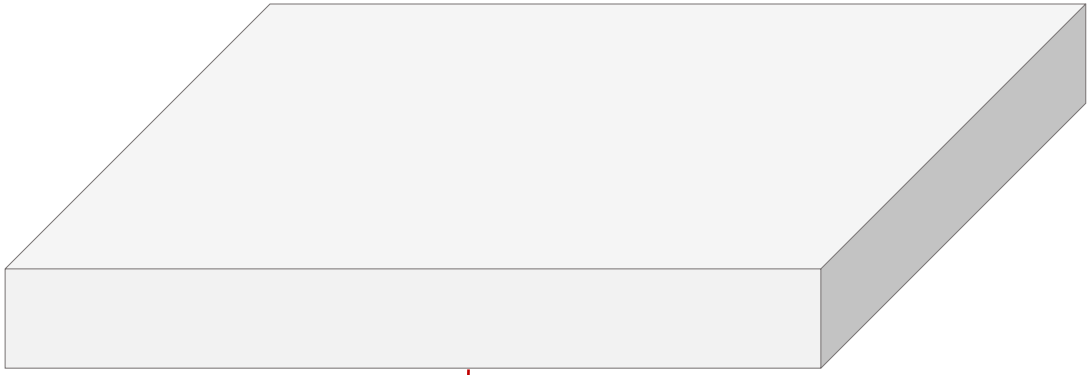
- SteelECThermal
- J2PlaneStressThermal

Concrete:

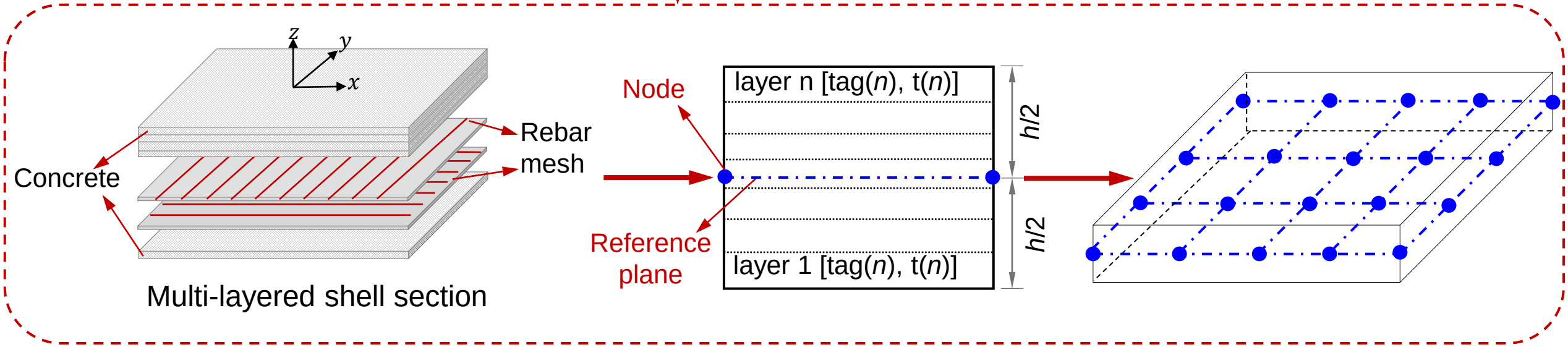
- CDPPlaneStressThermal

Evolution of composite slab models within OpenSees for fire framework

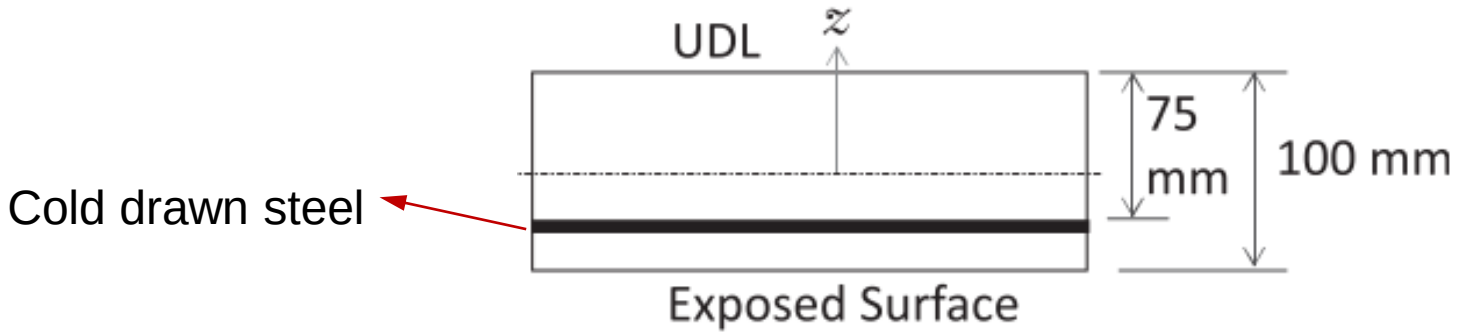
- Flat slab model



Discrete the section into multiple layers



Evolution of composite slab models within OpenSees for fire framework



Material

```
#Material defination
# Reinforcement Rebar mesh
#uniaxialMaterial SteelECThermal $matTag <$steelType> $Fy $E0;
uniaxialMaterial SteelECThermal 1 EC2NC $fy  $Es;
#nDMaterial PlateRebarThermal matTag MatTag orientation
nDMaterial PlateRebarThermal  2        1       0;
nDMaterial PlateRebarThermal  3        1       90;

#concrete
#nDMaterial CDPPlaneStressThermal $matTag $E0 $Poisson $ft $fc $gt $gc;
nDMaterial CDPPlaneStressThermal 5 $Ec 0.2 $ft $fc $gt $gc;
nDMaterial PlateFromPlaneStressThermal    4   5   1e9;
```

Steel type:
EC2NC (Cold drawn)
/EC2NH (Hot rolled)

Angle between rebar direction and the global X-axis

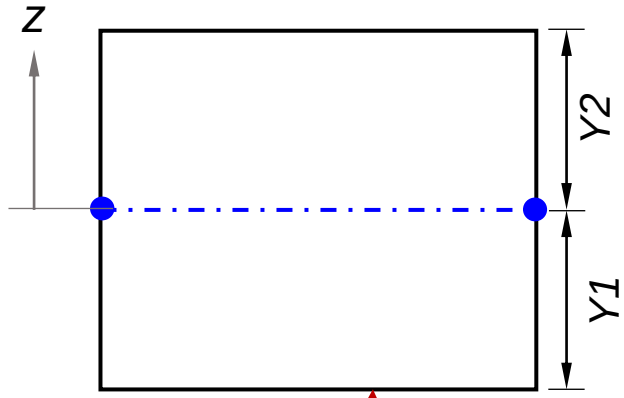
Section

```
#Section
#section LayeredShellThermal $secTag $layerNum $matTag $t $matTag $t  $matTag    $t...;
section LayeredShellThermal      1      13      4  0.008   4   0.008   4 [expr 0.009-$steellayer] 2 0.000565
```

Evolution of composite slab models within OpenSees for fire framework

Applying ambient load

```
#Applying ambient loads
set UDL 5.4E3;
set UDLP [expr -$UDL*$slabB*$slabL/$nx/$ny];

pattern Plain 1 Linear {
    set NumNodes [expr ($nx+1)*($ny+1)]
     for {set nodeID 1} {$nodeID<=$NumNodes} {incr nodeID} {
         load $nodeID 0 0 $UDLP 0 0 0 ;
         }
}
constraints Plain;
numberer Plain;
system BandGeneral;
test NormDispIncr 1e-3  300 1;
algorithm Newton;
integrator LoadControl 0.1;
analysis Static;
analyze 10;
```




```
loadConst -time 0.0
```

set load constant and reset time in the domain to be 0

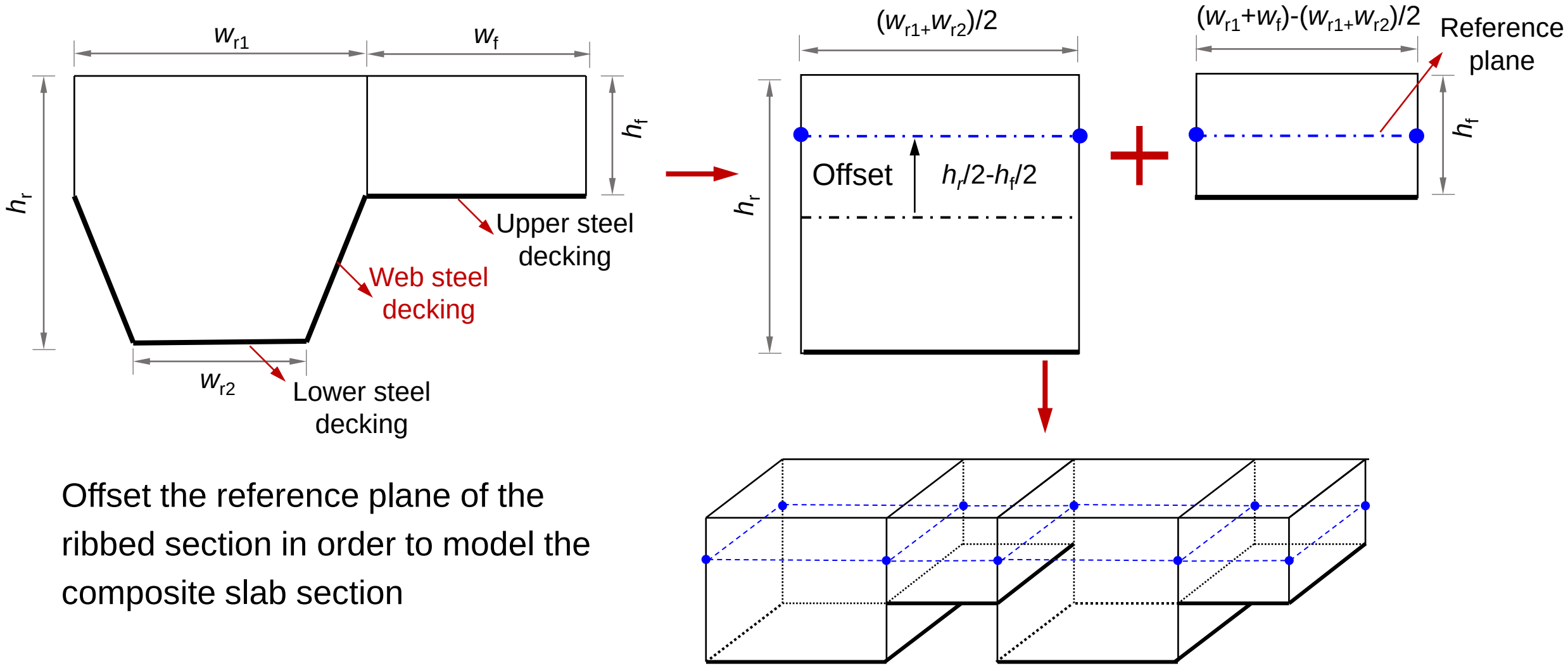
```
##########################################################################################
```

Applying thermal load

```
#Applying thermal loads
pattern Plain 2 Linear {
    #eleLoad -range firstEle lastEle    -type -shellThermal -source "fileName"       $Y1                $Y2
    eleLoad -range    1   [expr $nx*$ny] -type -shellThermal -source "slab.dat" [expr -$slabT/2] [expr $slabT/2]
    #eleLoad -range    1   [expr $nx*$ny] -type -shellThermal 800 [expr -$slabT/2] 150 [expr $slabT/2]
}
```

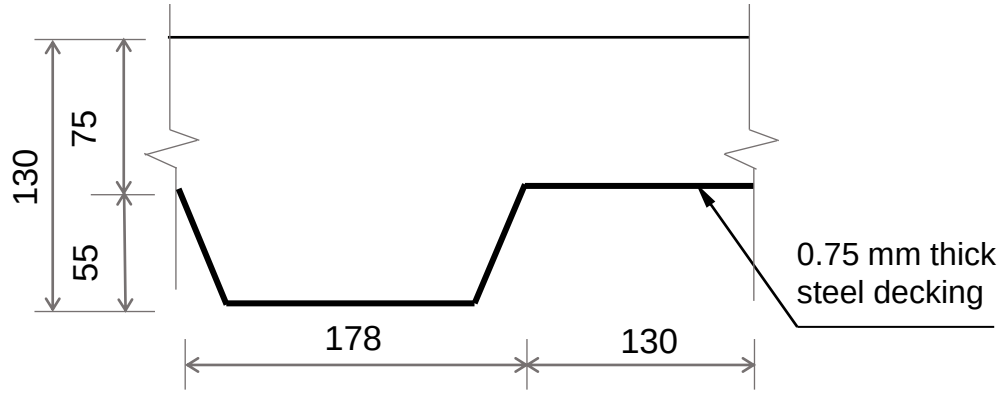
Evolution of composite slab models within OpenSees for fire framework

- V 1: Approximated composite slab model



Offset the reference plane of the ribbed section in order to model the composite slab section

Evolution of composite slab models within OpenSees for fire framework




```
##########################################################################

# Create sections
# Flat part section
set flatsec 1
#section LayeredShellThermal $secTag $layerNum $matTag $t $matTag $t  $matTag $t...;
section  LayeredShellThermal $flatsec   11      7    0.75e-3    5    0.01    5   0.01  3 $ro 2 $ro

# Rib section
set ribsec 2
#section LayeredShellThermal $secTag $layerNum -offset  $Dis  $matTag  $t  $matTag $t $matTag $t...
section  LayeredShellThermal $ribsec    17     -offset 0.0275    7  0.75e-3   5  0.01   5   0.01
```

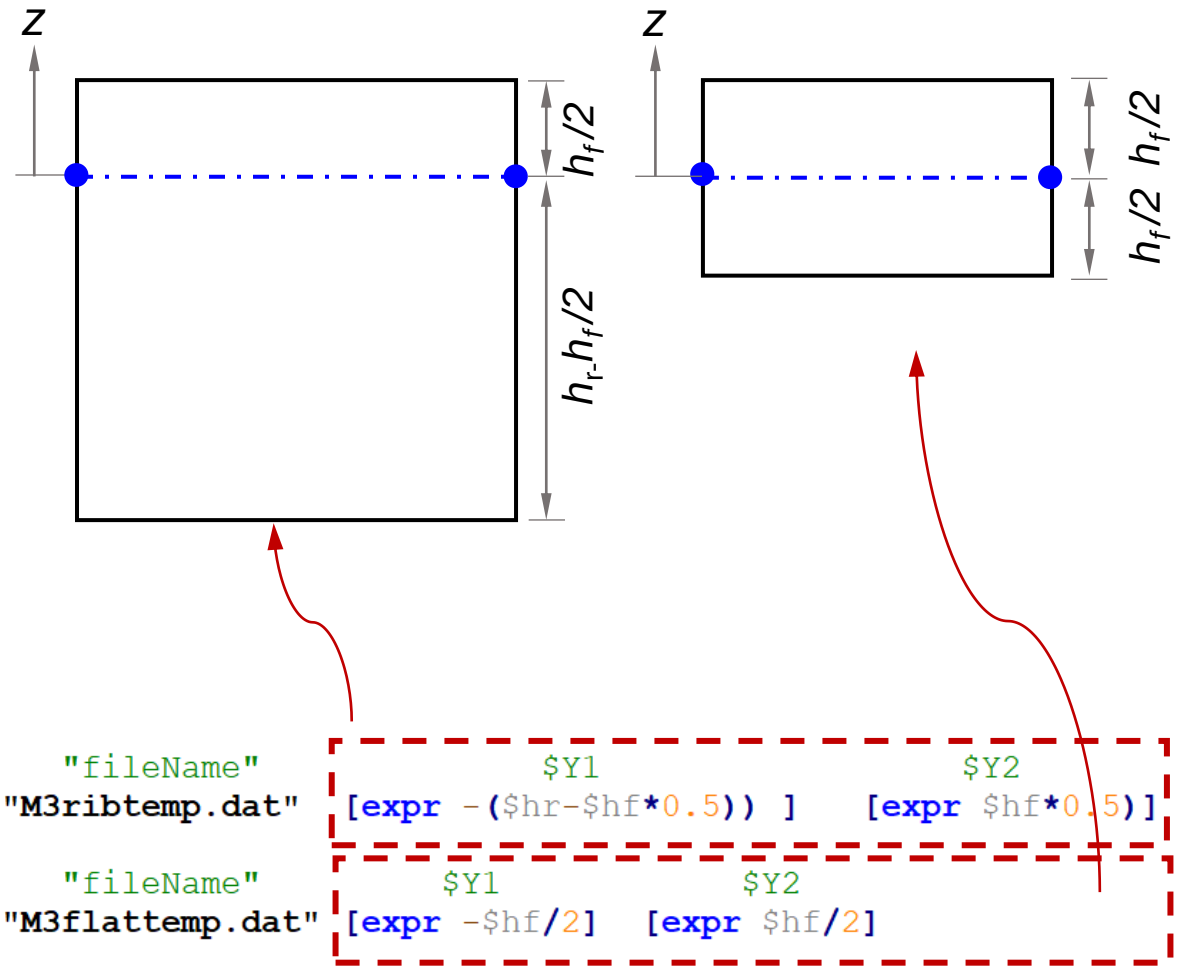
$h_r/2-h_f/2 = 130/2-75/2 = 27.5$ (mm)

Evolution of composite slab models within OpenSees for fire framework

Applying thermal load

```
# Applying thermal loads

pattern Plain 2 Linear {
   for {set i 1} {$i <= $nx} {incr i 1} {
      for {set j 1} {$j<=($endNode2-1)} {incr j 1} {

            set eleID [expr ($i-1)*($endNode2-1)+$j]

            if {$j%3==2} {
            set sec "rib"
            } else {
            set sec "flat"
            }

            if {$sec=="rib"} {
            #eleLoad -ele $eleID -type -shellThermal -source    "fileName"
            eleLoad  -ele $eleID -type -shellThermal -source "M3ribtemp.dat"
            } elseif {$sec=="flat"} {
            #eleLoad -ele $eleID -type -shellThermal -source    "fileName"
            eleLoad  -ele $eleID -type -shellThermal -source "M3flattemp.dat"
            }
      }
   }
}
```

Identify the elements for ribs and flat parts



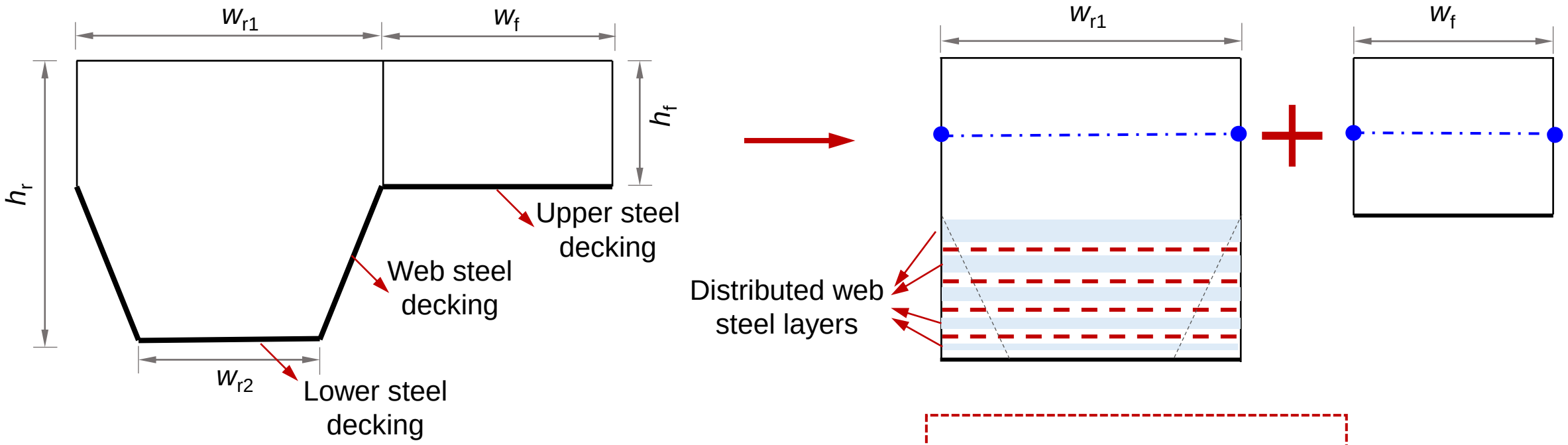
Evolution of composite slab models within OpenSees for fire framework

The ribbed section and flat section can be directly defined;
The cross-section with non-uniform thicknesses can be modelled using only shell elements via ‘offset’.

The tapered ribs are considered simply using a equivalent width;
The web profiled steel decking is ignored.

Evolution of composite slab models within OpenSees for fire framework

- V 2: Composite slab model considering the tapered ribs



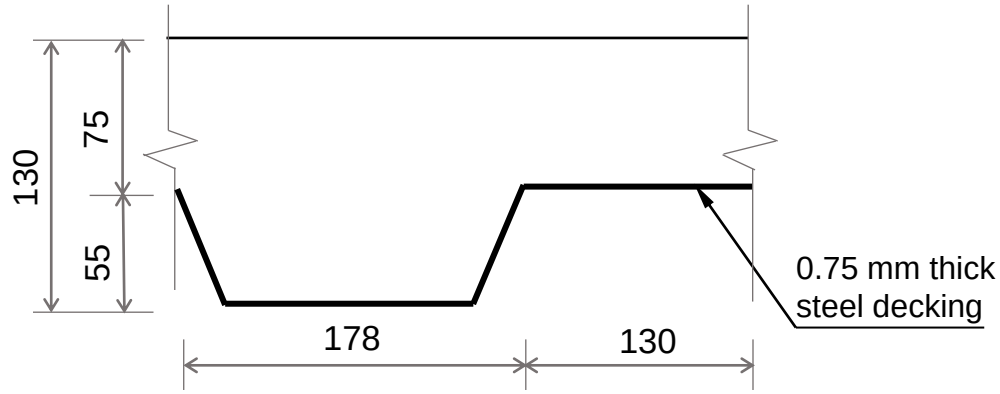
1. Considering the tapered ribs based on area equivalent method
2. Web profiled steel decking is modelled by the distributed steel layers

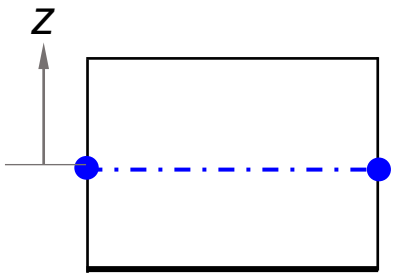
Area equivalent method:

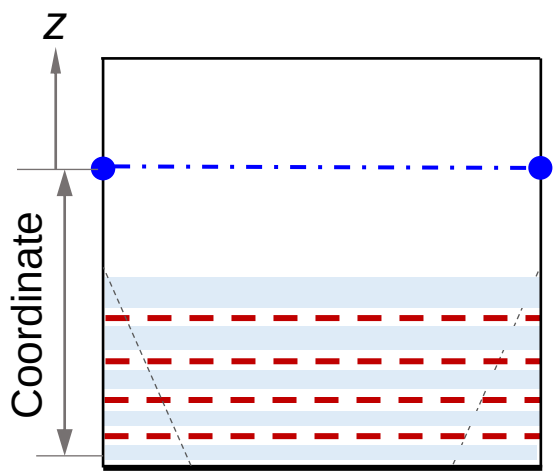
$$t_c'(j) = \frac{w(j) \cdot t(j)}{w_{r1}}$$

$$t_s' = \frac{2 \cdot l \cdot t_s}{n \cdot w_{r1}}$$

Evolution of composite slab models within OpenSees for fire framework








```
# Create sections

# Flat section
set flatsec 1
#section LayeredShellThermal $secTag $layerNum $matTag $t $matTag $t ...
section  LayeredShellThermal $flatsec   11       20    $dt   5   0.01  5 0.01    3 $ro  2 $ro

# Rib section
set ribsec 2
#section LayeredShellThermal $secTag -Rib $hf   $hr-$hf $Degree $layerNum $matTag $t    $coordinate
section  LayeredShellThermal $ribsec -Rib 0.075 0.055    0.0        21        20 0.00054 -0.092125
```

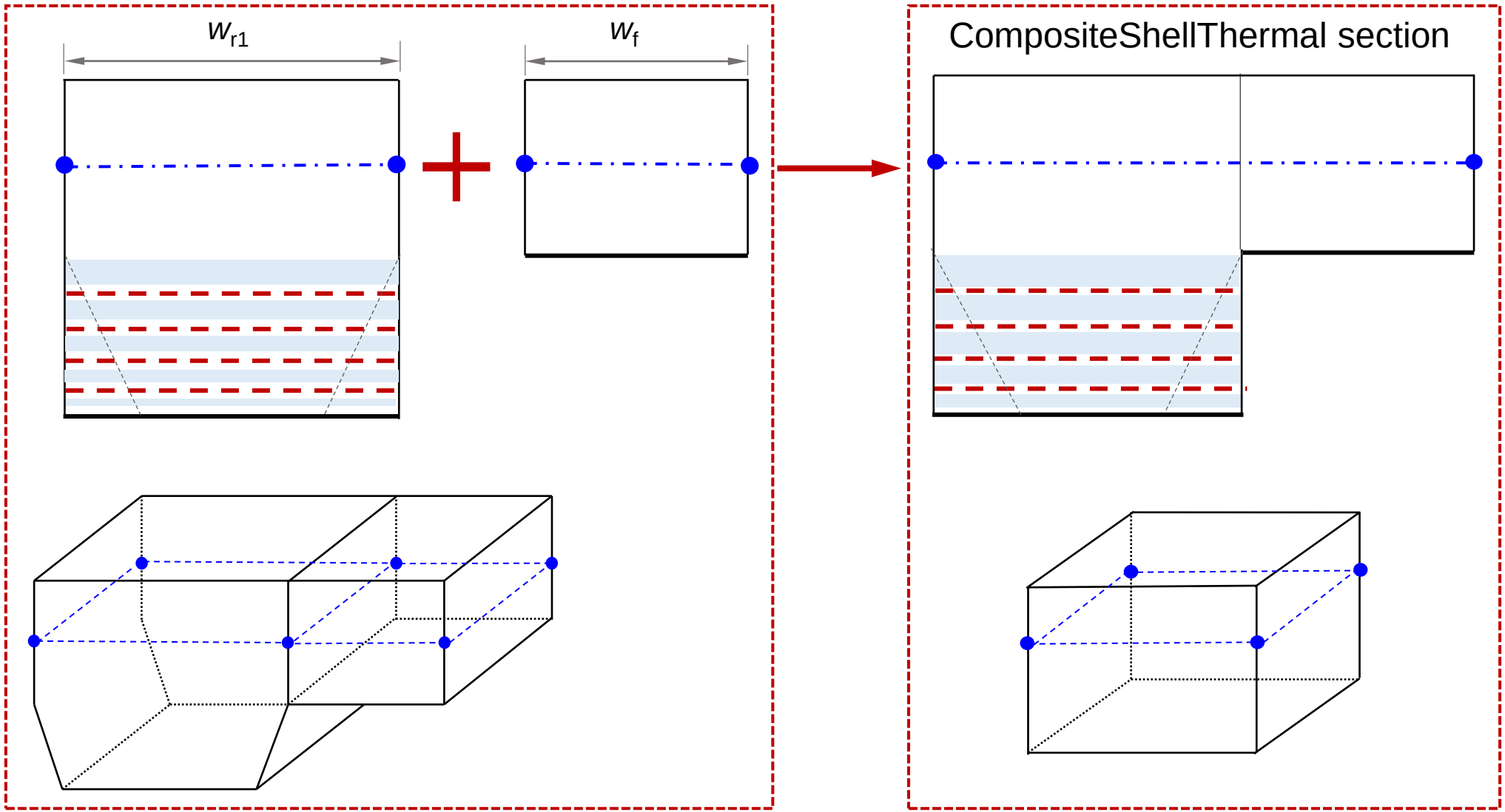
Evolution of composite slab models within OpenSees for fire framework

The tapered ribs can be considered more accurately;
The web profiled steel decking is well considered.

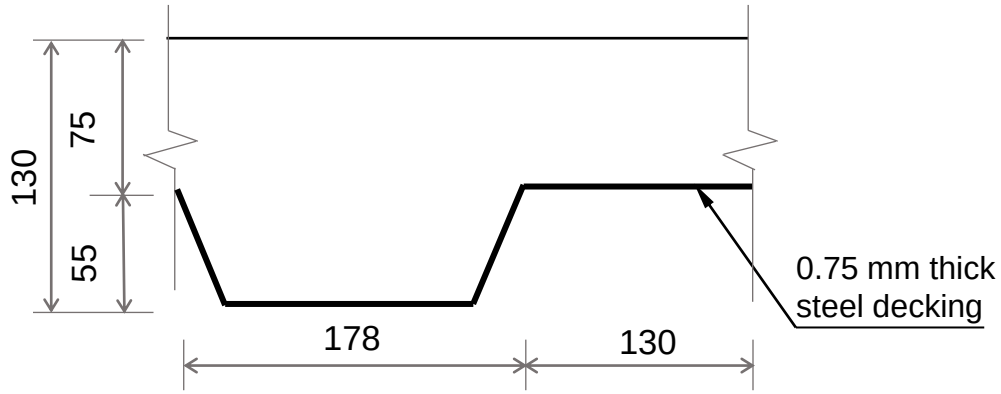
We still need to distinguish the ribs and flat parts when defining nodes, elements as well as applying loads

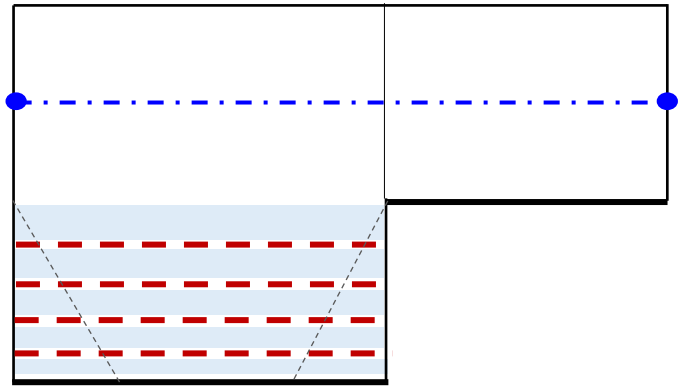
Evolution of composite slab models within OpenSees for fire framework

- V 3: Composite slab model with integrated composite section



Evolution of composite slab models within OpenSees for fire framework

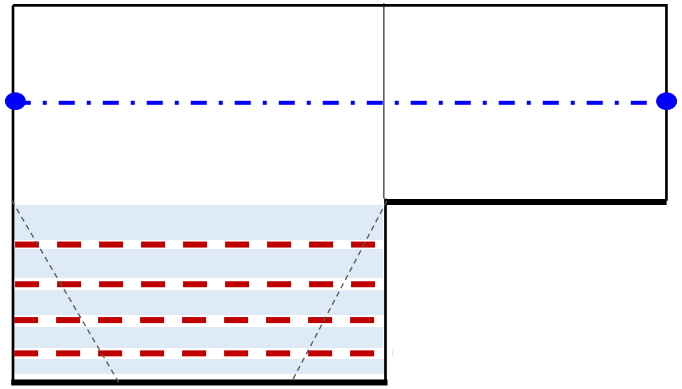




```
# Create sections

# Flat part section
set flatsec 1
#section LayeredShellThermal $secTag $layerNum $matTag $t  $matTag $t $matTag $t...;
section  LayeredShellThermal $flatsec    11      20  0.75e-3   5  0.01   5   0.01   3 $ro  2 $ro

# Rib section
set ribsec 2
#section LayeredShellThermal $secTag -Rib $hf  $hr-$hf $Degree $layerNum $matTag $t   $coordinate
section  LayeredShellThermal $ribsec -Rib 0.075 0.055    0.0       21       20 0.00054 -0.092125

set Compsec 3
#section CompositeShellThermal $secTag  $ribSec $r1 $flatSec $r2 $Degree $Error $Step
section CompositeShellThermal  $Compsec $ribsec 0.6 $flatsec 0.4  0.0      0.1   10;
```

r1 = 178/(178+130)
r2 = 130/(178+130)

Evolution of composite slab models within OpenSees for fire framework



```
#########################################################################################

pattern Plain 2 Linear {

  for {set i 1} {$i <= $nx} {incr i 1} {
     for {set j 1} {$j<=$ny} {incr j 1} {
        set eleID [expr int($j*100+$i)]
       #eleLoad -ele $eleTag -type -shellThermal -Twosource   "fileName1"     $Y11   $Y12  "fileName2"        $Y21     $Y22
        eleLoad -ele $eleID  -type -shellThermal -Twosource "M3ribtemp.dat" -0.0925 0.0375 "M3flattemp.dat" -$HalfT $HalfT;
      }
    }
}
#########################################################################################
```

Defining node

Defining element

Applying ambient load

Applying thermal load

```
for {set i 0} {$i <= $nx} {incr i 1} {
    set x [expr $i*$elemx]
    for {set j 0} {$j <= $ny} {incr j 1} {
        if {$j<=1} {
        set y [expr $j*$elemy3]
        }   elseif {$j%2 == 0} {
        set y [expr $elemy3+(($j-2)/2)*($elemy2+$elemy1)+$elemy1]
        }   elseif {$j%2 == 1} {
        set y [expr $elemy3+(($j-1)/2)*($elemy2+$elemy1)]
        }
        set nodeID [expr int(($j+1)*100+$i+1)]
        node $nodeID $x $y $flatH
    }
}
```

```
for {set i 0} {$i <= $nx} {incr i 1} {
    set x [expr $i*$elemx]
    for {set j 0} {$j <= $ny} {incr j 1} {
        set y [expr $j*$elemy]
        set nodeID [expr int(($j+1)*100+$i+1)]
        node $nodeID $x $y $flatH
    }
}
```

```
for {set i 1} {$i <= $nx} {incr i 1} {
    for {set j 1} {$j <= $ny} {incr j 1} {
       if {$j%2==0} {
        set sec $ribsec
      }  else {
        set sec $flatsec
      }
        set node1 [expr int($j*100+$i) ]
        set node2 [expr $node1 +1]
        set node3 [expr int(($j+1)*100+$i+1)]
        set node4 [expr $node3 - 1]
        set elemID $node1
         element ShellNLDKGQThermal  $elemID $node1 $node2 $node3 $node4 $sec
    }
}
```

```
for {set i 1} {$i <= $nx} {incr i 1} {
    for {set j 1} {$j <= $ny} {incr j 1} {
        set node1 [expr int($j*100+$i) ]
        set node2 [expr $node1 +1]
        set node3 [expr int(($j+1)*100+$i+1)]
        set node4 [expr $node3 - 1]

        set elemID $node1
         element ShellNLDKGQThermal  $elemID $node1 $node2 $node3 $node4 $Compsec
    }
}
```

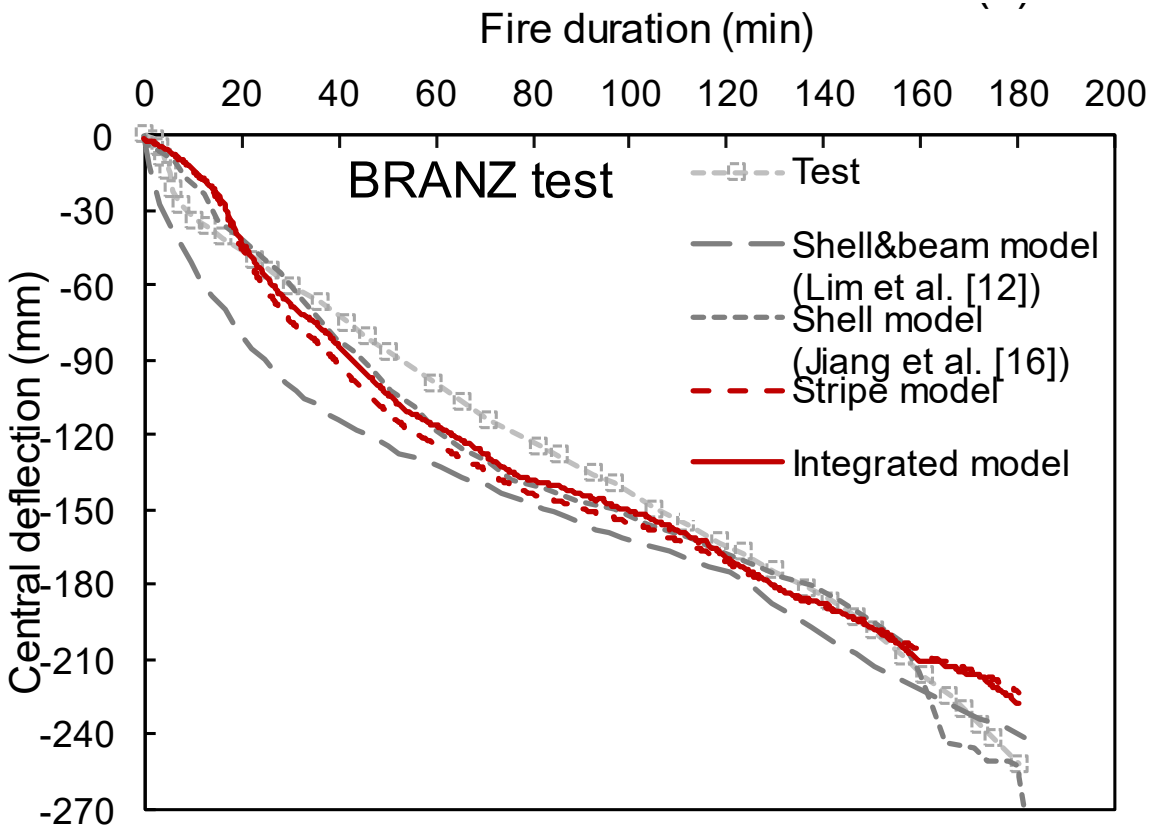
```
set f3r [expr $UDL*$elemx*$elemy1]
set f3f [expr $UDL*$elemx*$elemy2]
set f3f2 [expr $UDL*$elemx*$elemy3]
pattern Plain 1 Linear {
    for {set i 0} {$i <= $nx} {incr i 1} {
        for {set j 0} {$j<=$ny} {incr j 1} {
        if {$j==0} {
        set f3 [expr $f3f2/2]
        } elseif {$j==$ny} {
        set f3 [expr $f3f/2]
        } elseif {$j==1 } {
        set f3 [expr 0.5*($f3r+$f3f2)]
        } else {
        set f3 [expr 0.5*($f3f+$f3r)]
        }
        set nodeID [expr ($j+1)*100+$i+1]
            load  $nodeID   0   0   $f3  0    0    0
        }
    }
}
```

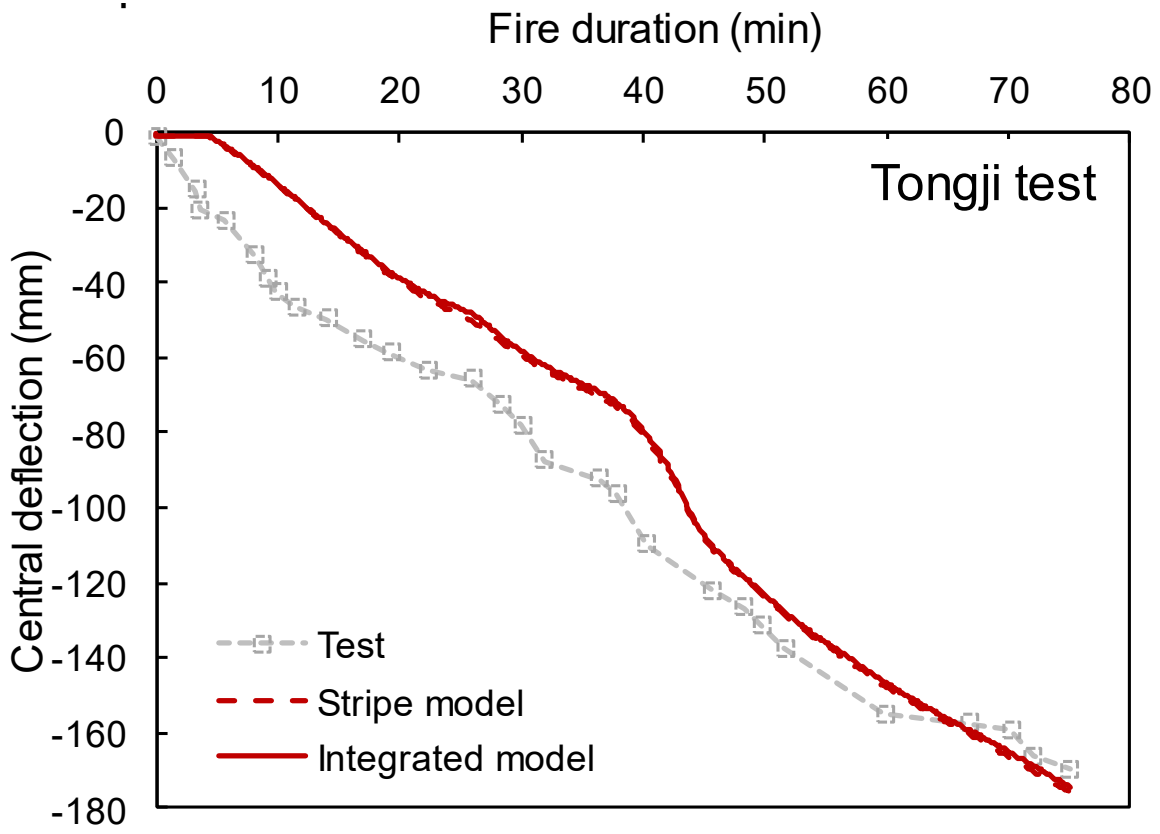
```
set f3 [expr $UDL*$elemx*$elemy]
pattern Plain 1 Linear {
    for {set i 0} {$i <= $nx} {incr i 1} {
      for {set j 0} {$j<=$ny} {incr j 1} {
        set nodeID [expr ($j+1)*100+$i+1]
        load  $nodeID   0   0   $f3  0    0    0
      }
    }
}
```

```
pattern Plain 2 Linear {
   for {set i 1} {$i <= $nx} {incr i 1} {
      for {set j 1} {$j<=($ny)} {incr j 1} {
          if {$j%2==0} {
          set sec "rib"
          } else {
          set sec "flat"
          }
          if {$sec=="rib"} {
          eleLoad  -ele [expr int($j*100+$i)]  -type -shellThermal -source "M3ribtemp.dat"    -0.0925    0.0375
          } elseif {$sec=="flat"} {
          eleLoad  -ele [expr int($j*100+$i)]  -type -shellThermal -source "M3flattemp.dat"    -$HalfT    $HalfT
          }
      }
   }
}
```

```
pattern Plain 2 Linear {
   for {set i 1} {$i <= $nx} {incr i 1} {
      for {set j 1} {$j<=$ny} {incr j 1} {
        set eleID [expr int($j*100+$i)]
        eleLoad -ele $eleID  -type -shellThermal -Twosource "M3ribtemp.dat" -0.0925 0.0375 "M3flattemp.dat" -$HalfT $HalfT;
      }
   }
}
```

Evolution of composite slab models within OpenSees for fire framework





Evolution of composite slab models within OpenSees for fire framework

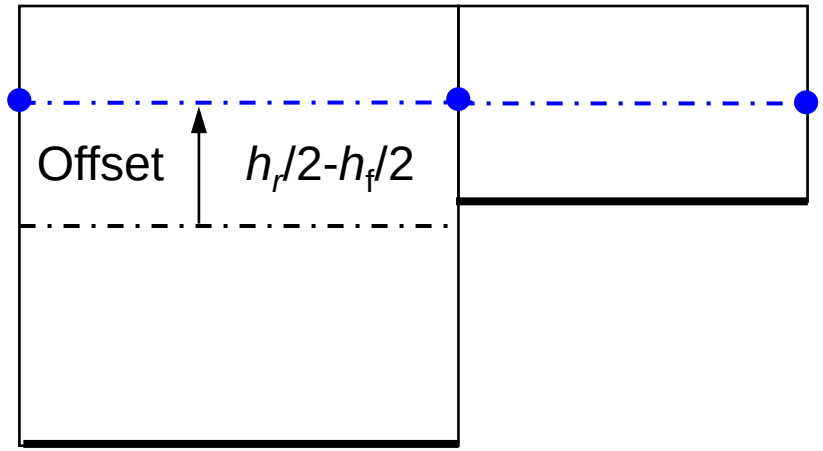
Efficiency comparison of adopting V2 composite slab model and V3 composite slab model

Type of slab model	Number of model components			Peak deflection (mm)	Computation time (s)
	Nodes	Elements	Links		
Shell&beam model [25]	780	708	486	405.0	-
Stripe model	1281	1200	215	434.3	5288
Integrated model_1	651	600	125	427.8	5110
Integrated model_2	247	216	73	416.1	1551

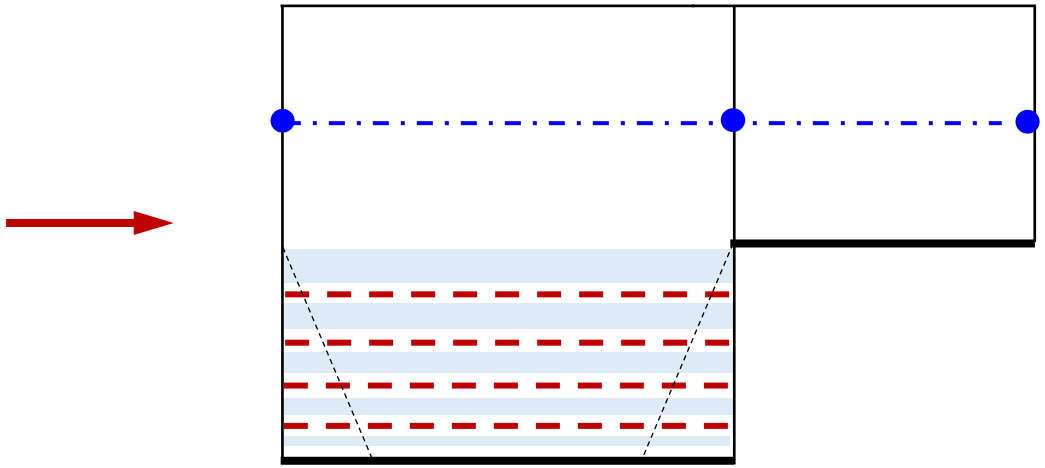
Qiu J, Jiang L, Orabi MA, Usmani A, Li G. A computational approach for modelling composite slabs in fire within OpenSees framework. ***Engineering Structures***, 2022;255:1–40.

Qiu J, Jiang L. An integrated section model to enable simulating composite slabs in fire simply as modelling a flat slab. **Computers & Structures**, (under review).

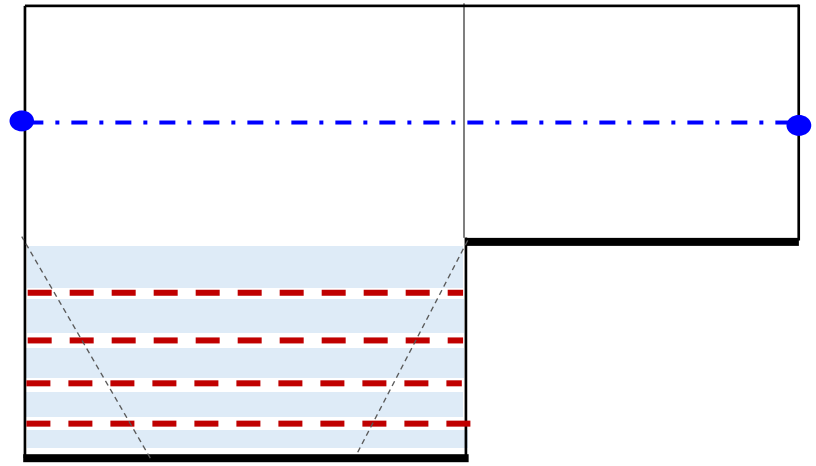
Evolution of composite slab models within OpenSees for fire framework



1. Offset reference plane



2. Tapered ribs



3. Integrated composite section

Thanks for your attention

Q&A

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