Study of fluid-structure interaction of Parc Vallparadís' footbridge using computational methods

ANNEX

Cristian Ariza

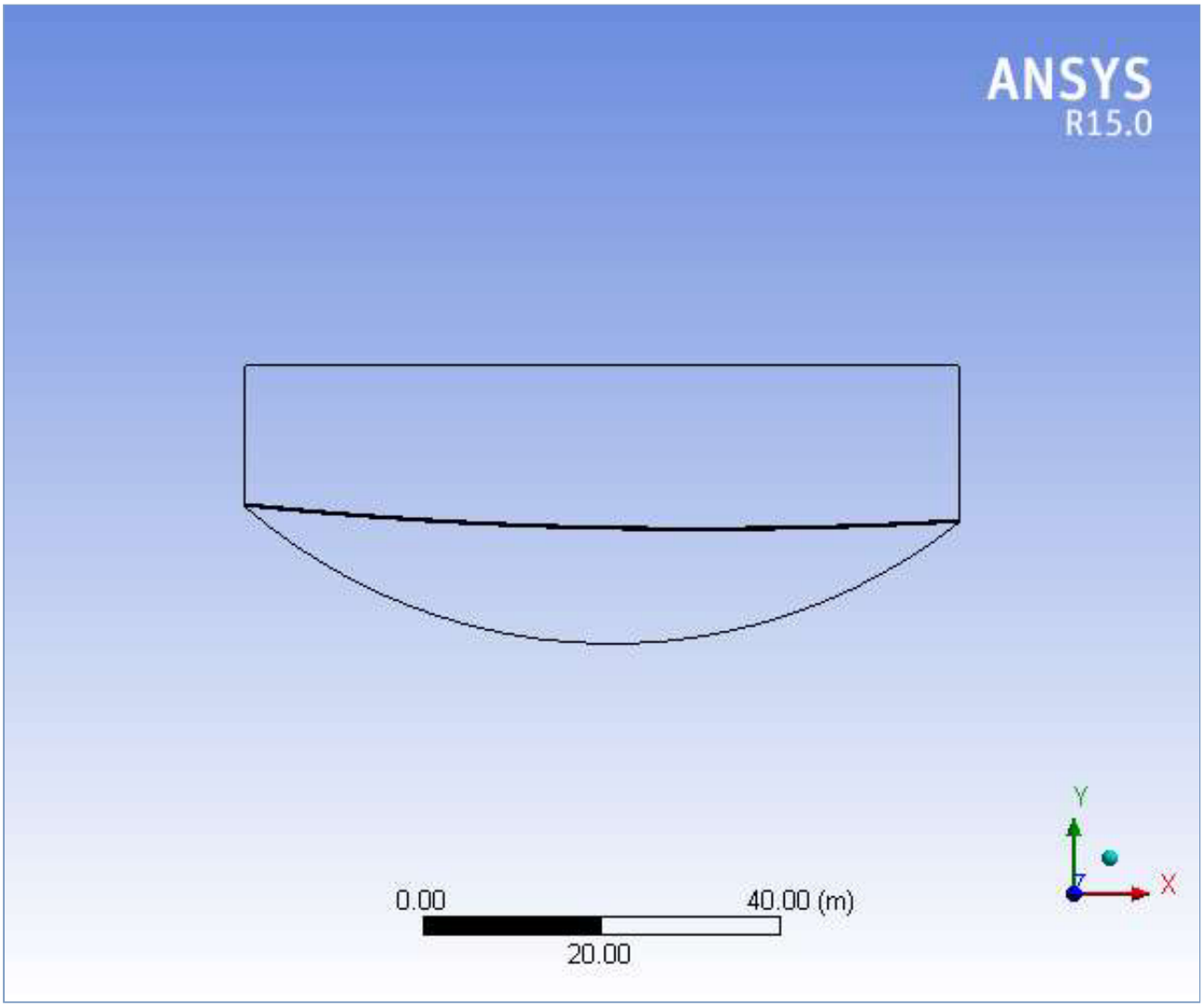
Appendix A

Fluid mesh report

--- ATTACHMENT ON NEXT PAGE ---

Project

First Saved	Saturday, July 18, 2015
Last Saved	Saturday, July 18, 2015
Product Version	15.0 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

- Units
- Model (A3)
  - Geometry
    - Parts
  - Coordinate Systems
  - Connections
  - Mesh
    - Mesh Controls
  - Named Selections

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A3)

Geometry

TABLE 2
Model (A3) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\Google Drive\TFG\ANSYS_Files\Footbridge\FSI_static_files\dp0\CFX\DM\CFX.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	79.997 m
Length Y	31.097 m
Length Z	32.4 m
Properties	
Volume	68690 m³
Scale Factor Value	1.
Statistics	
Bodies	2
Active Bodies	1
Nodes	193209
Elements	586067
Mesh Metric	Orthogonal Quality
Min	9.74578113666119E-02
Max	0.99911406296629
Average	0.806800733240761
Standard Deviation	0.122630972056487
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No

Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\crist_000\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3
Model (A3) > Geometry > Parts

Object Name	*pasarela_amb_contorn-1*	*fluid-1*
State	Suppressed	Meshed
Graphics Properties		
Visible	No	Yes
Transparency		1
Definition		
Suppressed	Yes	No
Coordinate System	Default Coordinate System	
Reference Frame	Lagrangian	
Material		
Fluid/Solid	Defined By Geometry (Solid)	
Bounding Box		
Length X	79.997 m	
Length Y	2.9333 m	31.097 m
Length Z	2.7 m	32.4 m
Properties		
Volume	45.491 m³	68690 m³
Centroid X	77.543 m	77.968 m
Centroid Y	68.922 m	72.867 m
Centroid Z	64.482 m	55.026 m
Statistics		
Nodes	0	193209
Elements	0	586067
Mesh Metric	Orthogonal Quality	
Min	0	9.74578113666119E-02
Max	0	0.99911406296629
Average	0	0.806800733240761
Standard Deviation	0	0.122630972056487

Coordinate Systems

TABLE 4
Model (A3) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m

Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A3) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

Mesh

TABLE 6
Model (A3) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Medium
Num Cells Across Gap	Default (3)
Proximity Min Size	0.10 m
Max Face Size	Default (4.57270 m)
Max Size	Default (9.14530 m)
Growth Rate	1.50
Minimum Edge Length	9.8472e-003 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.77
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	CFD
Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled

Defeaturing	
Pinch Tolerance	5.e-002 m
Generate Pinch on Refresh	Yes
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	8.e-002 m
Statistics	
Nodes	193209
Elements	586067
Mesh Metric	Orthogonal Quality
Min	9.74578113666119E-02
Max	0.99911406296629
Average	0.806800733240761
Standard Deviation	0.122630972056487

TABLE 7
Model (A3) > Mesh > Mesh Controls

Object Name	*Inflation*	*Face Sizing*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	Named Selection
Geometry	1 Body	
Named Selection		bridge
Definition		
Suppressed	No	
Boundary Scoping Method	Named Selections	
Boundary	bridge	
Inflation Option	First Layer Thickness	
First Layer Height	3.e-002 m	
Maximum Layers	5	
Growth Rate	1.3	Default
Inflation Algorithm	Pre	
Type		Element Size
Element Size		0.3 m
Behavior		Soft
Local Min Size		0.2 m

Named Selections

TABLE 8
Model (A3) > Named Selections > Named Selections

Object Name	*bridge*	*inlet*	*outlet*	*floor*	*free stresm*
State	Fully Defined				
Scope					
Scoping Method	Worksheet	Geometry Selection			
Geometry	8 Faces	1 Face			3 Faces
Definition					
Send to Solver	Yes				
Visible	Yes				
Program Controlled Inflation	Exclude				
Statistics					
Type	Manual				
Total Selection	8 Faces	1 Face			3 Faces
Suppressed	0				
Used by Mesh Worksheet	No				
Tolerance					
Tolerance Type	Program Controlled				
Zero Tolerance	1.e-008				
Relative Tolerance	1.e-003				

Appendix B

Modal analysis mathematical development

The linear equation that describes the vibration of an undamped body is

$$[M]\{\ddot{u}\} + [K]\{u\} = \{0\}$$

The harmonic motion is defined as:

$$\begin{cases} \{u\} & = \{\phi\}_i \sin(\omega_i t + \theta_i) \\ \{\ddot{u}\} & = -\omega_i^2 \{\phi\}_i \sin(\omega_i t + \theta_i) \end{cases}$$

Therefore,

$$-\omega_i^2 \{u\} = \{\ddot{u}\}$$

Substituting

$$[M](-\omega_i^2 \{u\}) + [K]\{u\} = \{0\}$$

Dividing both sides by $\sin(\omega_i t + \theta_i)$

$$[M]\left(-\omega_i^2 \{\phi\}_i\right) + [K]\{\phi\}_i = \{0\}$$

$$([K] - \omega_i^2 [M])\{\phi\}_i = \{0\}$$

Appendix C

Mesh approaches

	Changes	Elements	Average Skewness	Average Ort. Quality	Elements* (%)	Skewness* (%)	Ort. quality* (%)
Mesh 0	-	586067	0.3500	0.8100	-	-	-
Mesh 1	Smooth transition Transition ratio 0.77 Max. layers 5 Growth rate 1.3	569133	0.3560	0.8110	2.8894	-1.7143	0.1235
Mesh 2	Transition ratio 0.5	588454	0.3570	0.8030	-3.3948	-0.2809	-0.9864
Mesh 3	Maximum layers 6	633940	0.3600	0.7990	-7.7297	-0.8403	-0.4981
Mesh 4	Without face sizing	628244	0.3620	0.7970	0.8985	-0.5556	-0.2503
Mesh 5	Total thickness 0.3	623206	0.3620	0.8024	0.8019	-0.0026	0.6805
Mesh 6	Number of layers +1	672722	0.3620	0.8024	-7.9454	0.0000	0.0000
Mesh 7	Layers 6 Growth rate 1.4	612663	0.3621	0.8051	8.9278	-0.0180	0.3281
Mesh 8	Layers 7 Max thickness 0.3	672716	0.3656	0.7934	-9.8020	-0.9799	-1.4493
Mesh 9	Growth rate 1.1 Layers 6	622489	0.3578	0.8093	7.4663	2.1441	2.0048
Mesh 10	Growth rate 1.2	623064	0.3601	0.8056	-0.0924	-0.6352	-0.4620
Mesh 11	Layers 7 Thickness .4	656435	0.3611	0.8096	-5.3560	-0.2964	0.5027
Mesh 12	Thickness .45	650410	0.3611	0.8117	0.9178	-0.0034	0.2564

[1]

[1]* The percentage values represent the variation respect the old value, also the signs of the values are changed in the way that (+) signs denote an improvement and (-) a decrease in the parameter for better visualization.

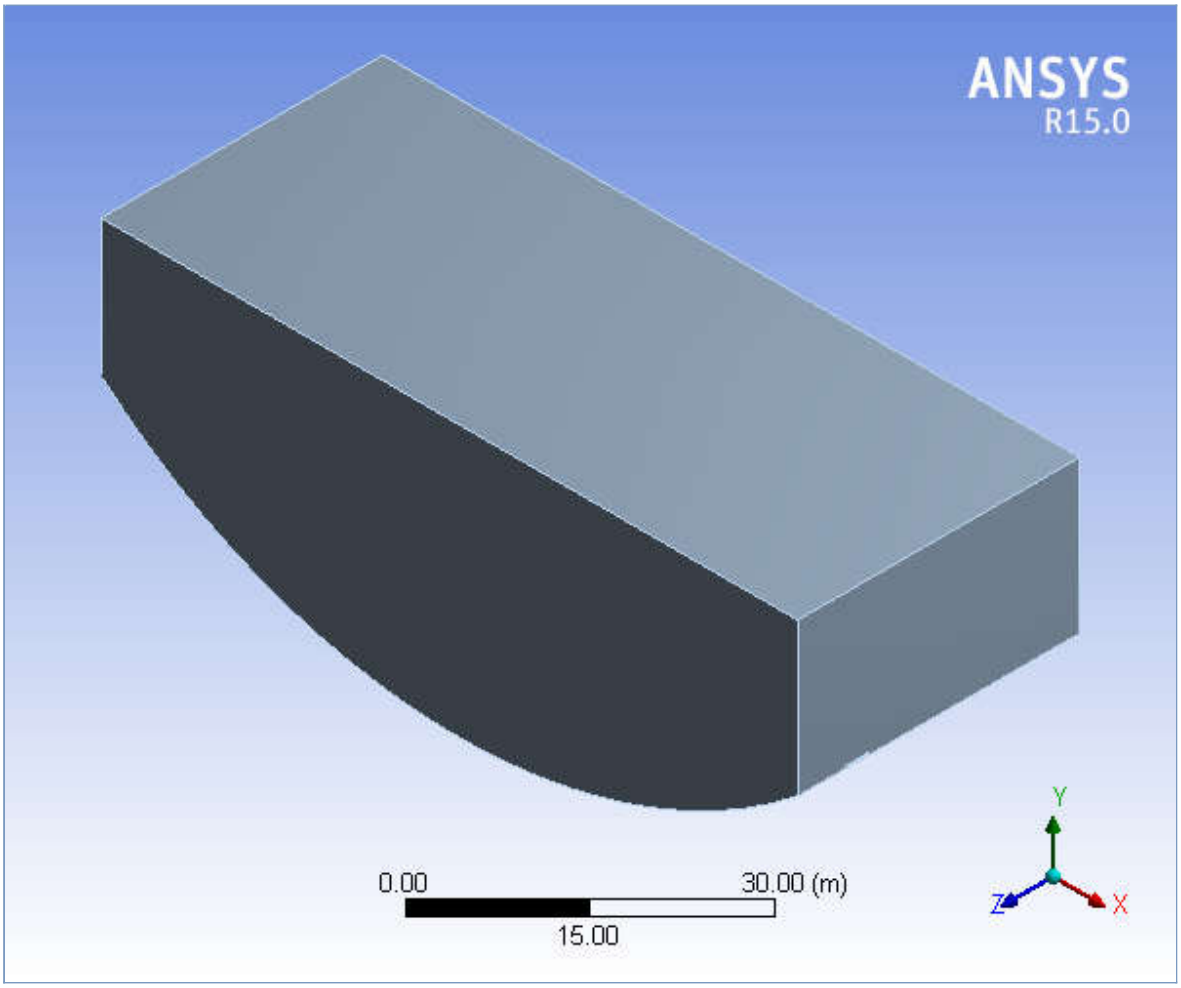
Appendix D

Second mesh report

--- ATTACHMENT ON NEXT PAGE ---

Project

First Saved	Saturday, July 18, 2015
Last Saved	Friday, September 11, 2015
Product Version	15.0 Release
Imported Source	E:\Google Drive\TFG\ANSYS_Files\Footbridge\persidecas\mesh.meshdat
Imported Version	15.0 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

- Units
- Model (A3, B3)
  - Geometry
    - Parts
  - Coordinate Systems
  - Connections
  - Mesh
    - Mesh Controls
  - Named Selections

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A3, B3)

Geometry

TABLE 2
Model (A3, B3) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\TFG_ANSYS\FSI_Static_files\dp0\SYS-1\DM\SYS-1.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	79.997 m
Length Y	31.097 m
Length Z	32.4 m
Properties	
Volume	68690 m³
Scale Factor Value	1.
Statistics	
Bodies	2
Active Bodies	1
Nodes	233781
Elements	650410
Mesh Metric	Skewness
Min	4.11138694966451E-04
Max	0.985536613768205
Average	0.361135496222047
Standard Deviation	0.154573517225982

Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\crist_000\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3
Model (A3, B3) > Geometry > Parts

Object Name	*pasarela_amb_contorn-1*	*fluid-1*
State	Suppressed	Meshed
Graphics Properties		
Visible	No	Yes
Transparency		1
Definition		
Suppressed	Yes	No
Coordinate System	Default Coordinate System	
Reference Frame	Lagrangian	
Material		
Fluid/Solid	Defined By Geometry (Solid)	
Bounding Box		
Length X	79.997 m	
Length Y	2.9333 m	31.097 m
Length Z	2.7 m	32.4 m
Properties		
Volume	45.491 m³	68690 m³
Centroid X	77.543 m	77.968 m
Centroid Y	68.922 m	72.867 m
Centroid Z	64.482 m	55.026 m
Statistics		
Nodes	0	233781
Elements	0	650410
Mesh Metric	Skewness	
Min	0	4.11138694966451E-04
Max	0	0.985536613768205
Average	0	0.361135496222047
Standard Deviation	0	0.154573517225982

Coordinate Systems

TABLE 4
Model (A3, B3) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (A3, B3) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

Mesh

TABLE 6
Model (A3, B3) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Medium
Num Cells Across Gap	Default (3)
Proximity Min Size	0.10 m
Max Face Size	Default (4.57270 m)
Max Size	Default (9.14530 m)
Growth Rate	1.50
Minimum Edge Length	9.8472e-003 m
Inflation	
Use Automatic Inflation	None

Inflation Option	Smooth Transition
Transition Ratio	0.77
Maximum Layers	5
Growth Rate	1.3
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	CFD
Element Midside Nodes	Dropped
Straight Sided Elements	
Number of Retries	0
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	5.e-002 m
Generate Pinch on Refresh	Yes
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	8.e-002 m
Statistics	
Nodes	233781
Elements	650410
Mesh Metric	Skewness
Min	4.11138694966451E-04
Max	0.985536613768205
Average	0.361135496222047
Standard Deviation	0.154573517225982

TABLE 7
Model (A3, B3) > Mesh > Mesh Controls

Object Name	*Inflation*	*Face Sizing*
State	Fully Defined	Suppressed
Scope		
Scoping Method	Geometry Selection	Named Selection
Geometry	1 Body	
Named Selection		bridge
Definition		
Suppressed	No	Yes
Boundary Scoping Method	Named Selections	
Boundary	bridge	
Inflation Option	Total Thickness	
Number of Layers	7	
Growth Rate	1.2	Default
Maximum Thickness	0.45 m	
Inflation Algorithm	Pre	
Active		No, Suppressed
Type		Element Size

Element Size		0.3 m
Behavior		Soft
Local Min Size		0.2 m

Named Selections

TABLE 8
Model (A3, B3) > Named Selections > Named Selections

Object Name	*bridge*	*inlet*	*outlet*	*floor*	*free stream*
State	Fully Defined				
Scope					
Scoping Method	Worksheet	Geometry Selection			
Geometry	8 Faces	1 Face			3 Faces
Definition					
Send to Solver	Yes				
Visible	Yes				
Program Controlled Inflation	Exclude				
Statistics					
Type	Manual				
Total Selection	8 Faces	1 Face			3 Faces
Suppressed	0				
Used by Mesh Worksheet	No				
Tolerance					
Tolerance Type	Program Controlled				
Zero Tolerance	1.e-008				
Relative Tolerance	1.e-003				

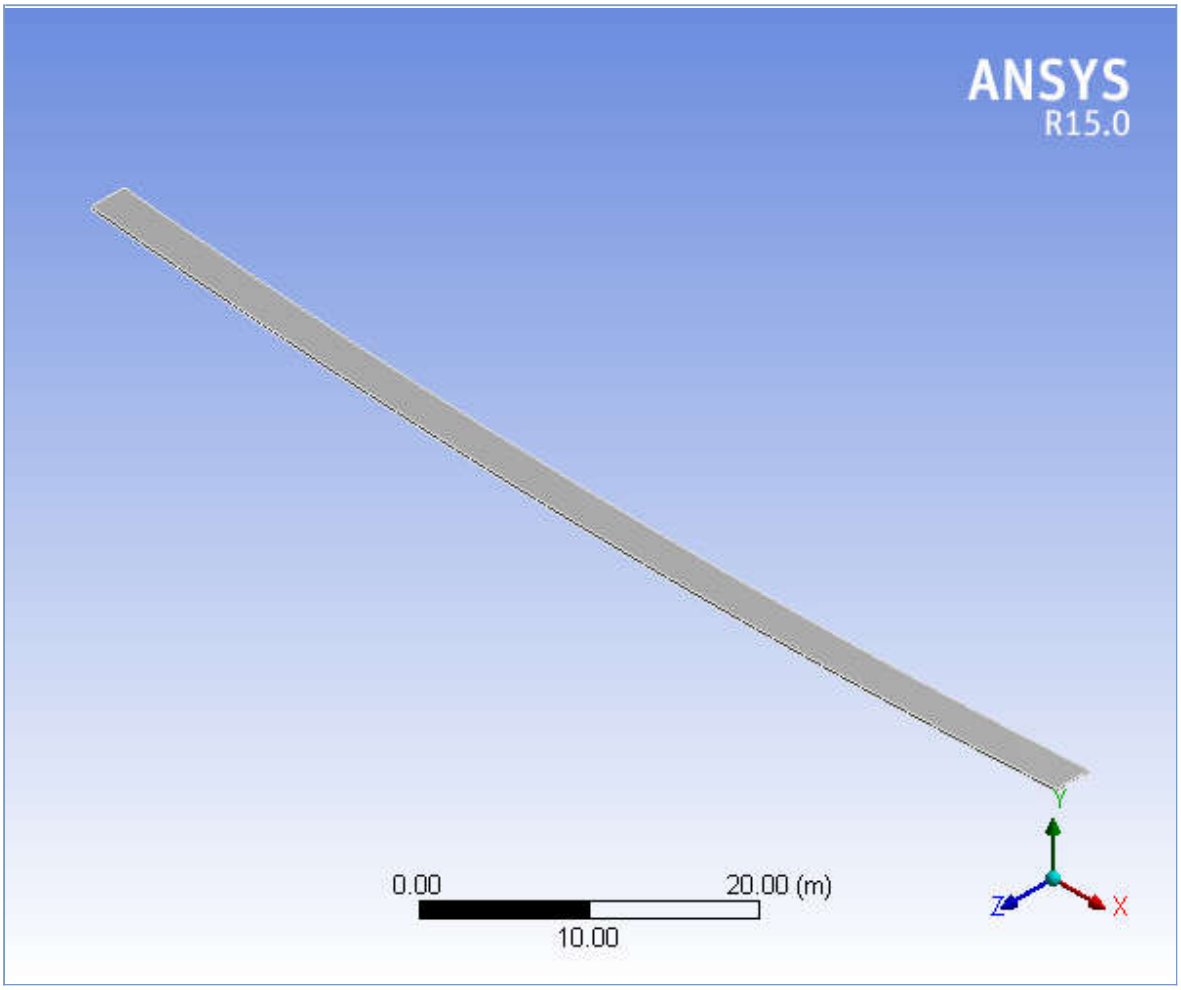
Appendix E

ANSYS Mechanical report

--- ATTACHMENT ON NEXT PAGE ---

Project

Author	Cristian Ariza
First Saved	Wednesday, July 22, 2015
Last Saved	Thursday, October 1, 2015
Product Version	15.0 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

- **Units**
- **Model (C4)**
  - Geometry
    - Parts
  - Coordinate Systems
  - Connections
    - Contacts
      - Contact Region
  - Mesh
    - Body Sizing
  - **Static Structural (C5)**
    - Analysis Settings
    - Loads
    - Imported Load (B5)
      - Imported Pressure
    - Solution (C6)
      - Solution Information
      - Results
- **Material Data**
  - Concrete

Units

TABLE 1

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (C4)

Geometry

TABLE 2
Model (C4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\TFG_ANSYS\FSI_Static_files\dp0\SYS-1\DM\SYS-1.agdb
Type	DesignModeler
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	79.997 m
Length Y	31.097 m

Length Z	32.4 m
Properties	
Volume	45.491 m³
Mass	1.0463e+005 kg
Scale Factor Value	1.
Statistics	
Bodies	2
Active Bodies	1
Nodes	747744
Elements	151798
Mesh Metric	None
Basic Geometry Options	
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\crist_000\AppData\Local\Temp
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE 3
Model (C4) > Geometry > Parts

Object Name	*pasarela_amb_contorn-1*	*fluid-1*
State	Meshed	Suppressed
Graphics Properties		
Visible	Yes	No
Transparency	1	
Definition		
Suppressed	No	Yes
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	Concrete	
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	79.997 m	
Length Y	2.9333 m	31.097 m
Length Z	2.7 m	32.4 m
Properties		
Volume	45.491 m³	68690 m³

Mass	1.0463e+005 kg	
Centroid X	77.543 m	77.968 m
Centroid Y	68.922 m	72.867 m
Centroid Z	64.482 m	55.026 m
Moment of Inertia Ip1	1.0162e+005 kg·m²	
Moment of Inertia Ip2	5.596e+007 kg·m²	
Moment of Inertia Ip3	5.5911e+007 kg·m²	
Statistics		
Nodes	747744	0
Elements	151798	0
Mesh Metric	None	

Coordinate Systems

TABLE 4
Model (C4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. m
Origin Y	0. m
Origin Z	0. m
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (C4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 6
Model (C4) > Connections > Contacts

Object Name	*Contacts*
State	Suppressed
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider

Tolerance Slider	0.
Tolerance Value	0.22935 m
Use Range	No
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies

TABLE 7
Model (C4) > Connections > Contacts > Contact Regions

Object Name	*Contact Region*
State	Suppressed
Scope	
Scoping Method	Geometry Selection
Contact	8 Faces
Target	No Selection
Contact Bodies	pasarela_amb_contorn-1
Target Bodies	fluid-1
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	0.22935 m
Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Pinball Region	Program Controlled
Geometric Modification	
Contact Geometry Correction	None

Mesh

TABLE 8
Model (C4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly

Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	9.8472e-003 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	
Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	747744
Elements	151798
Mesh Metric	None

TABLE 9
Model (C4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Type	Element Size
Element Size	7.5e-002 m
Behavior	Soft

Static Structural (C5)

TABLE 10
Model (C4) > Analysis

Object Name	*Static Structural (C5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	25. °C
Generate Input Only	No

TABLE 11
Model (C4) > Static Structural (C5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	E:\TFG_ANSYS\FSI_Static_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	mks

TABLE 12

Model (C4) > Static Structural (C5) > Loads

Object Name	*Fixed Support*	*Force*	*Moment*	*Force 2*	*Moment 2*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	2 Faces	1 Face			
Definition					
Type	Fixed Support	Force	Moment	Force	Moment
Suppressed	No				
Define By		Components			
Coordinate System		Global Coordinate System			
X Component		0. N (ramped)	-3734.6 N·m (ramped)	0. N (ramped)	-3734.6 N·m (ramped)
Y Component		0. N (ramped)	0. N·m (ramped)	0. N (ramped)	0. N·m (ramped)
Z Component		-5775.1 N (ramped)	0. N·m (ramped)	-5775.1 N (ramped)	0. N·m (ramped)
Behavior			Deformable		Deformable
Advanced					
Pinball Region			All		All

FIGURE 1
Model (C4) > Static Structural (C5) > Force

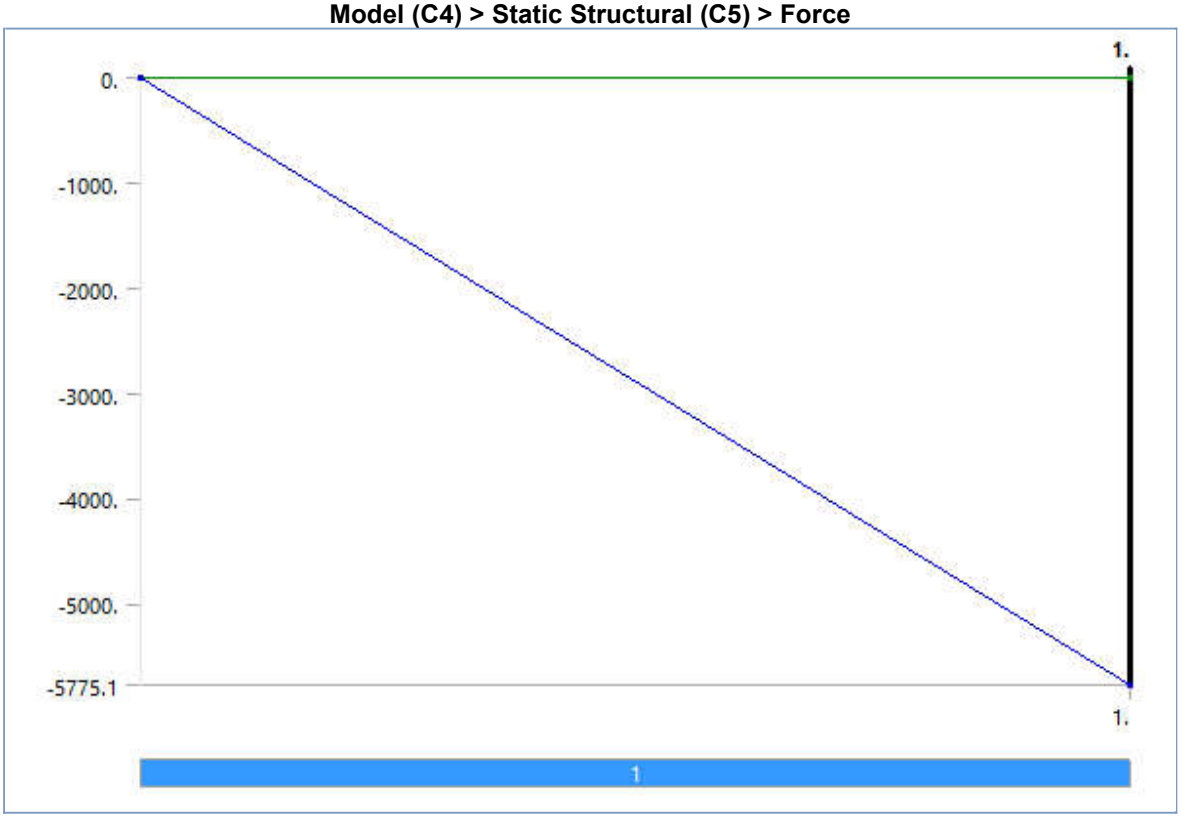


FIGURE 2
Model (C4) > Static Structural (C5) > Moment

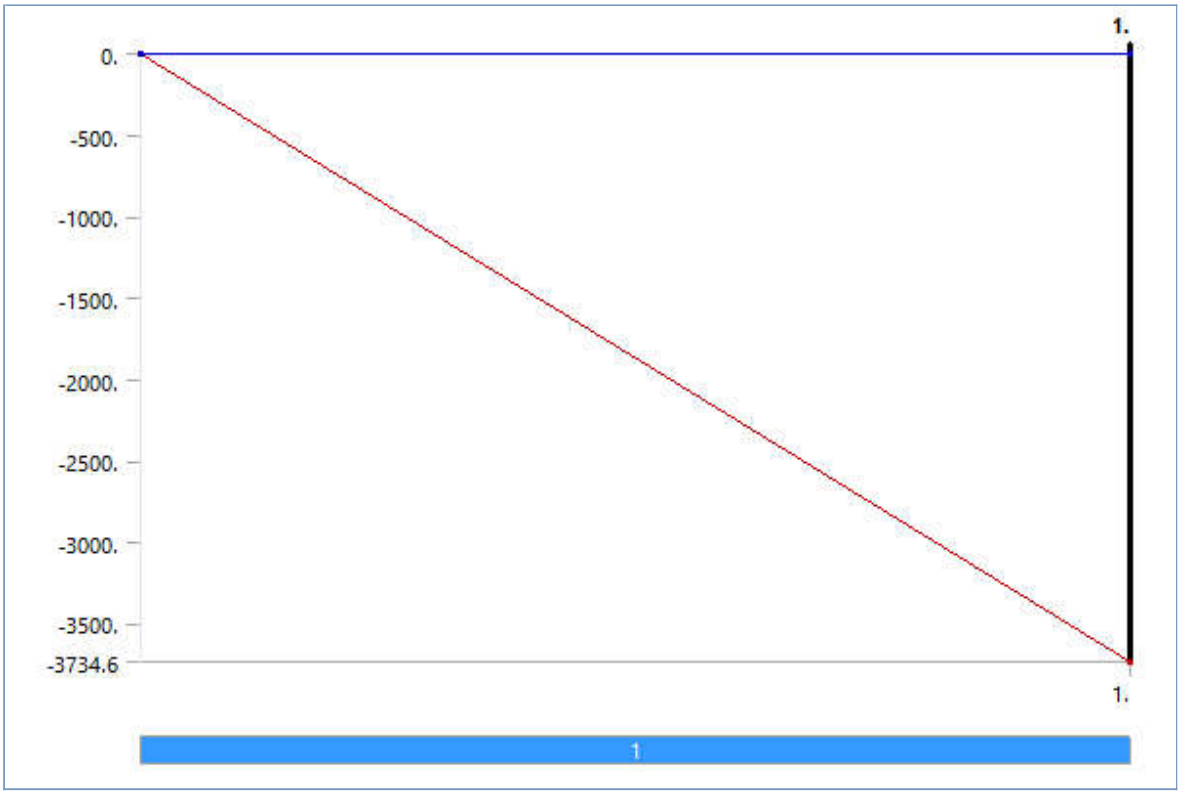


FIGURE 3
Model (C4) > Static Structural (C5) > Force 2

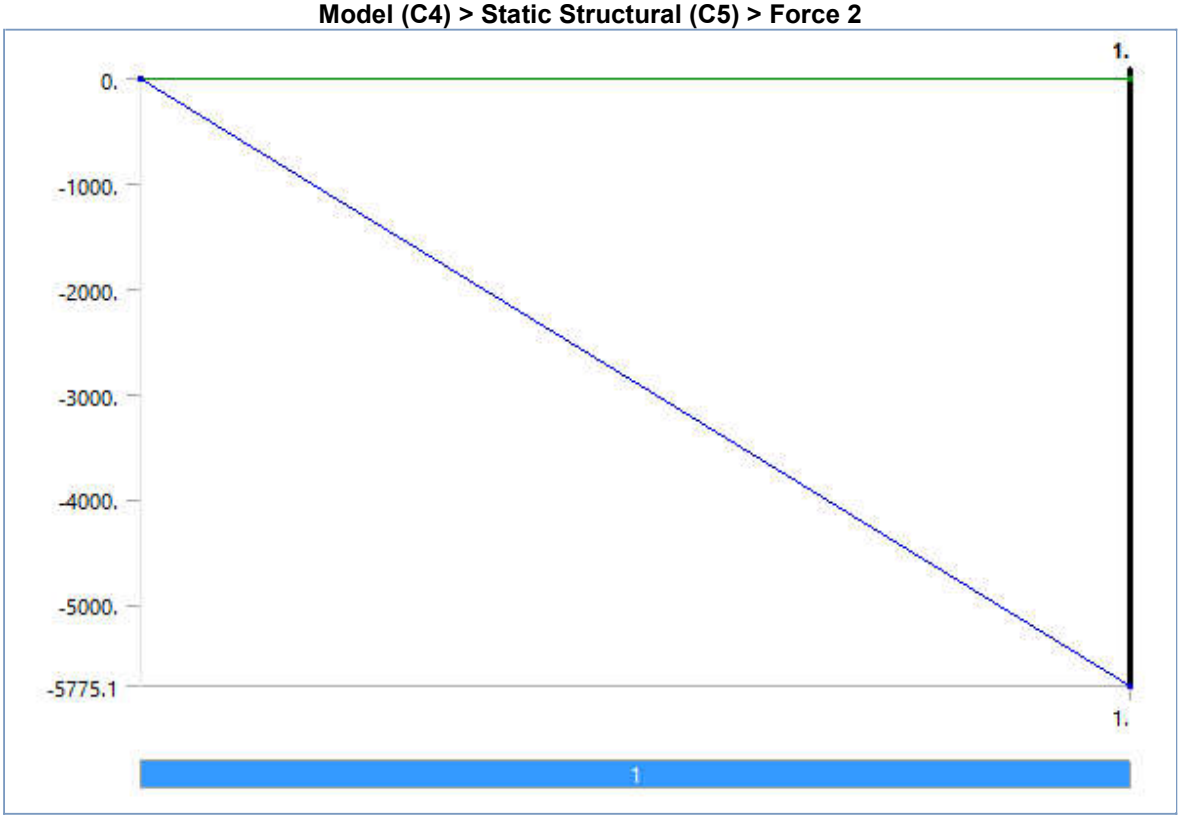


FIGURE 4
Model (C4) > Static Structural (C5) > Moment 2

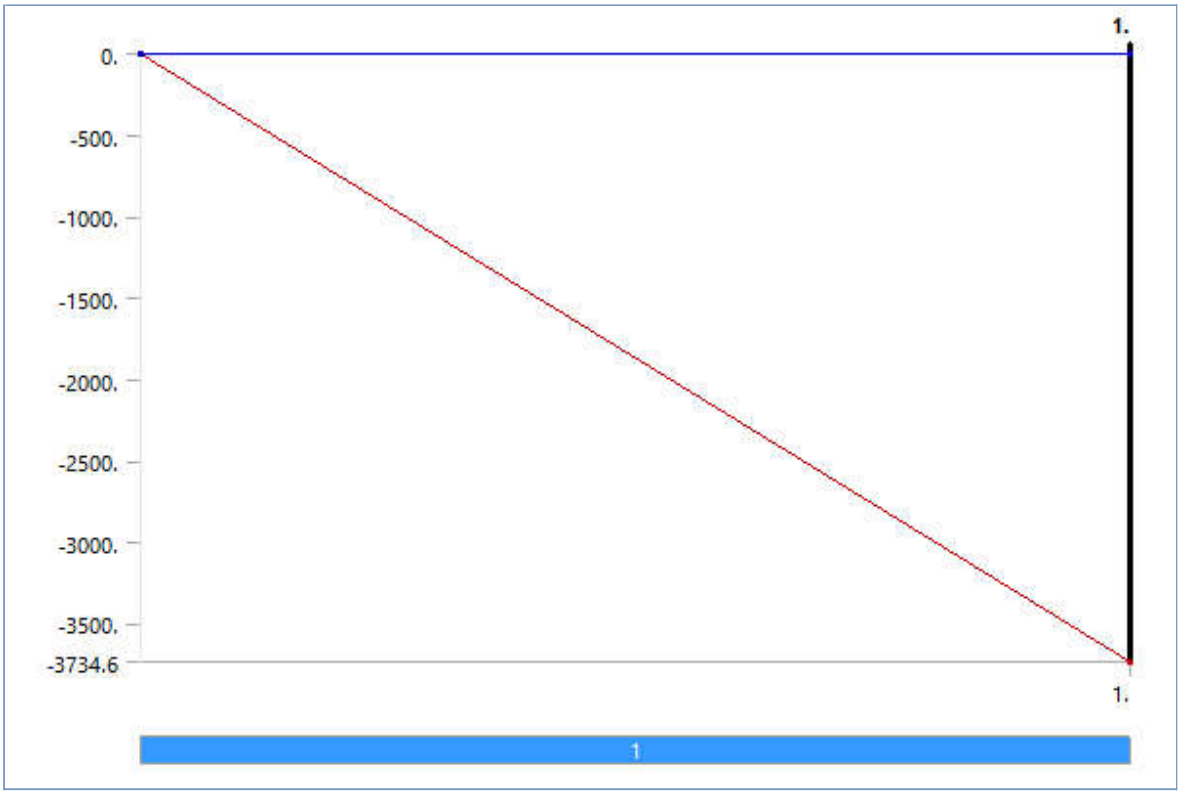


TABLE 13
Model (C4) > Static Structural (C5) > Imported Load (B5)

Object Name	*Imported Load (B5)*
State	Fully Defined
Definition	
Type	Imported Data
Interpolation Type	CFD Results Interpolator
Suppressed	No
Source	B5::Solution

TABLE 14
Model (C4) > Static Structural (C5) > Imported Load (B5) > Imported Pressure

Object Name	*Imported Pressure*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	10 Faces
Definition	
Type	Imported Pressure
Tabular Loading	Program Controlled
Suppressed	No
Graphics Controls	
Component	All
Transfer Definition	
CFD Surface	Default Domain Default
CFD Data	
CFD Results File	E:\TFG_ANSYS\FSI_Static_files\dp0\SYS\MECH\Solution\Fluid Flow CFX_002.res

Model (C4) > Static Structural (C5) > Imported Load (B5) > Imported Pressure

	Source Time (s)	Source Time Step	Analysis Time (s)	Scale	Offset (Pa)
1	0.	112.	1	1	0

Model (C4) > Static Structural (C5) > Imported Load (B5) > Imported Pressure > Imported Load Transfer Summary

CFD Load Transfer Summary

All values correspond to the CFD results before the application of any Scale or Offset operations set in Mechanical.

CFD Computed Forces from CFD Results File **E:\TFG_ANSYS\FSI_Static_files\dp0\SYS\MECH\Solution\Fluid Flow CFX_002.res**
X-component = 0.80135 N
Y-component = -7.0563e-004 N
Z-component = 1.2658e-004 N

Mechanical Mapped Forces for Mechanical Surface File **E:\TFG_ANSYS\FSI_Static_files\dp0\SYS\MECH\Import_ANSYS_41.cdb**
X-component = -413.47 N
Y-component = -8.4361 N
Z-component = -23.393 N

2% of Mechanical nodes were mapped to the CFD surface. The remaining nodes are mapped to the closest edge or node

Solution (C6)

TABLE 15
Model (C4) > Static Structural (C5) > Solution

Object Name	*Solution (C6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

TABLE 16
Model (C4) > Static Structural (C5) > Solution (C6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type

Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 17
Model (C4) > Static Structural (C5) > Solution (C6) > Results

Object Name	*Maximum Principal Stress*	*Middle Principal Stress*	*Minimum Principal Stress*	*Total Deformation*
State	Solved			
Scope				
Scoping Method	Geometry Selection			
Geometry	All Bodies			
Definition				
Type	Maximum Principal Stress	Middle Principal Stress	Minimum Principal Stress	Total Deformation
By	Time			
Display Time	Last			
Calculate Time History	Yes			
Identifier				
Suppressed	No			
Integration Point Results				
Display Option	Averaged			
Average Across Bodies	No			
Results				
Minimum	-25549 Pa	-40170 Pa	-2.3803e+005 Pa	0. m
Maximum	2.3846e+005 Pa	40332 Pa	26998 Pa	2.6845e-004 m
Minimum Value Over Time				
Minimum	-25549 Pa	-40170 Pa	-2.3803e+005 Pa	0. m
Maximum	-25549 Pa	-40170 Pa	-2.3803e+005 Pa	0. m
Maximum Value Over Time				
Minimum	2.3846e+005 Pa	40332 Pa	26998 Pa	2.6845e-004 m
Maximum	2.3846e+005 Pa	40332 Pa	26998 Pa	2.6845e-004 m
Information				
Time	1. s			
Load Step	1			
Substep	1			
Iteration Number	1			

Material Data

Concrete

TABLE 18
Concrete > Constants

Density	2300 kg m^-3
Coefficient of Thermal Expansion	1.4e-005 C^-1
Specific Heat	780 J kg^-1 C^-1
Thermal Conductivity	0.72 W m^-1 C^-1

TABLE 19

Concrete > Compressive Ultimate Strength

Compressive Ultimate Strength Pa
4.1e+007

TABLE 20
Concrete > Compressive Yield Strength

Compressive Yield Strength Pa
0

TABLE 21
Concrete > Tensile Yield Strength

Tensile Yield Strength Pa
0

TABLE 22
Concrete > Tensile Ultimate Strength

Tensile Ultimate Strength Pa
5.e+006

TABLE 23
Concrete > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature C
22

TABLE 24
Concrete > Isotropic Elasticity

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
	3.e+010	0.18	1.5625e+010	1.2712e+010

Appendix F

Critical divergence speed demonstration

$$M_\theta = \frac{1}{2}\rho v^2 b^2 C_M(\theta)$$

$$M_\theta(0) = \frac{1}{2}\rho U^2 b^2 C_{M,0}$$

$$M_\theta = \frac{1}{2}\rho v^2 b^2 \left[c_{M,0} + \left(\frac{dc_M}{d\theta}\right)_{\theta=0}\theta\right]$$

$$\frac{1}{2}\rho v^2 b^2 \left[c_{M,0} + \left(\frac{dc_M}{d\theta}\right)_{\theta=0}\theta\right] = k_\theta \theta$$

Setting $\lambda = \frac{1}{2}\rho v^2 b^2$:

$$\left(k_\theta - \lambda c'_{M,0}\right)\theta = \lambda c_{M,0} \qquad \Rightarrow \qquad \theta = \frac{\lambda c_{M,0}}{k_\theta - \lambda c'_{M,0}}$$

The divergence occurs when θapproaches infinity, therefore, when $\lambda = \frac{k_\theta}{c'_{M,0}}$. Which gives the final equation:

$$v_c = \sqrt{\frac{2k_\theta}{\rho b^2 c'_{M,0}}} = \sqrt{\frac{2k_\theta}{\rho b^2 \frac{dc_M}{d\theta}}}$$