Elastomeric Isolators for Nuclear Power Plants

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Summary

- Introduction to elastomeric isolators: HDRB & LRB
- Tests on scaled down prototypes (scale 1:2) - IRIS project
- Development of rubber compounds (low damping and high damping) and tests on prototypes up to 500 mm diameter – SILER project
- Design of HDRB and LRB – SILER project

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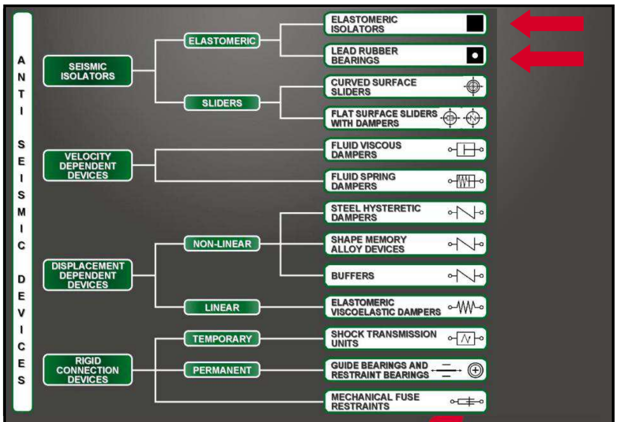

Classification according to European Standard on Antiseismic device, EN15129

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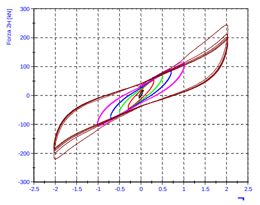
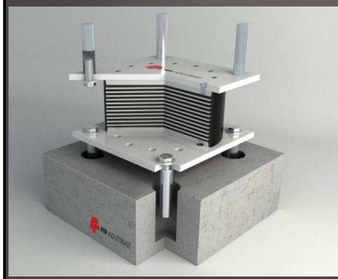
High damping rubber bearings

- $\xi = 10 \div 15$ %





FIP manufactured more than 8400 HDRB for seismic isolation of civil structures

For nuclear applications: prequalification by Cogema/Areva for isolators for Usine Georges Besse II, France

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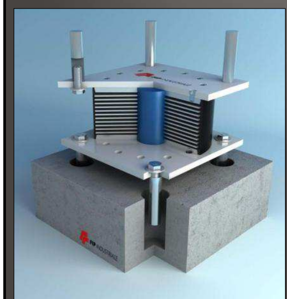
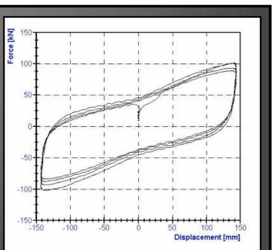
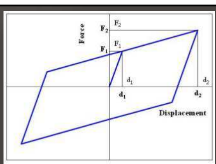
Lead rubber bearings

- $\xi = 20 \div 30$ %







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Lead rubber bearings

Type test on full scale isolators (Dia. 1100 mm) f=0.208 Hz, amplitude ± 324 mm (s.s.123 %)

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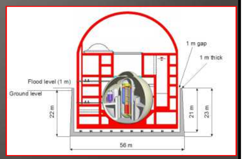
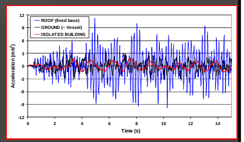
Reference Project: IRIS

(International Reactor Innovative and Secure)

- Medium size (335 MWe) reactor, International project coordinated by Westinghouse
- Design of the isolation system of the Nuclear Steam Supplier System made by ENEA, Politecnico of Milan & University of Pisa
- f_i=0.7 Hz
- PGA=0.3 g
- Displacement 100 mm
- 99 elastomeric isolators (HDRB) Dia. 1000 & 1300 mm, G=1.4 MPa, total rubber height 100 mm (100 % shear strain)





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IRIS Project - Type tests on isolators

- 6 prototypes: 1:2 scale of Dia. 1000 mm isolators; 500 mm diameter (1st step; full scale tests will be carried out in the 2nd step)
- Characterization tests (compression, compression–shear, quasi-static, dynamic, up to 1.5 Hz, up to s.s. 150 %)
- Failure tests:
  - in compression
  - in shear (+compression)

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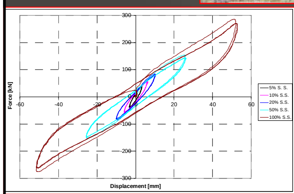
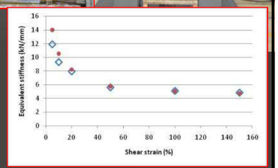
IRIS Project - Dynamic tests

- f=0.7 Hz, increasing amplitudes (shear strain ± 5%, ± 10%, ± 20%, ± 50%, ± 100% and ± 150%)
- f= 0.1, 0.5, 1, 1.5 Hz, s.s. 100%
- CESI laboratory





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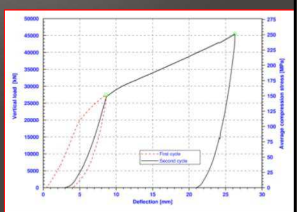
IRIS Project - Failure test in compression

- FIP Industriale laboratory
- 1 isolator tested
- quasi-static test
- 1st cycle: V increased up to 27450 kN (152 MPa), then removed: NO FAILURE
- 2nd cycle: V increased up to failure at 45444 kN (251 MPa)
- Note: yielding of steel laminae according to EN 1337:3 at 7650 kN (42 MPa)



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IRIS Project - Failure test in compression

failure at 45444 kN (251 MPa), ≈ 23 times the design vertical load

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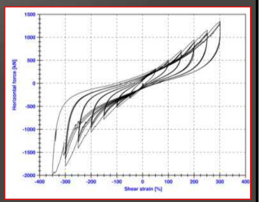
IRIS Project – Failure tests in shear-compression



- FIP Industriale laboratory
- 2 isolators tested in double-shear configuration
- V=2000 kN (11 MPa)
- quasi-static test
- increasing amplitudes (s.s.± 50%, ± 100%, ± 150%, ± 200%, ± 250%, ± 300%, 3 cycles per amplitude, then +350 %)
- NO DAMAGE

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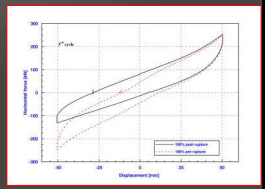
IRIS Project – Failure tests in shear-compression



- 1 isolator tested in single-shear configuration
- V=2000 kN (11 MPa)
- quasi-static test
- increasing amplitudes (s.s. ± 50%, ± 100%; +100%: -150%, -200%, -250%, -300%, -350%,-400%), 3 cycles per amplitude
- failure at about 380 % s.s. (3.8 times the design value)
- repetition of test at ± 100% s.s. after failure: reduction of stiffness

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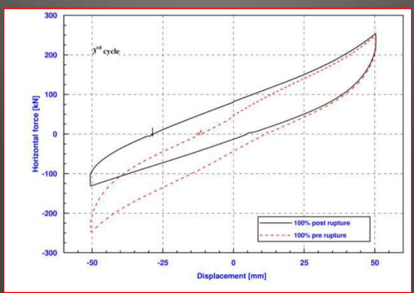
IRIS Project – Failure tests in shear-compression



the operational capacity (i.e. ability to sustain vertical & horizontal loads) of the isolator is guaranteed even after an important damage

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SILER Project
Development of rubber compounds

- Objectives:
- High damping rubber compound for HDRB
  $\xi \geq 10$ % at s.s. 100% and f=0.5 Hz
  G_{dyn}=1.4 MPa (selected after design of HDRB)
- Low damping rubber compound for LRB
  G_{dyn}=1.4 MPa

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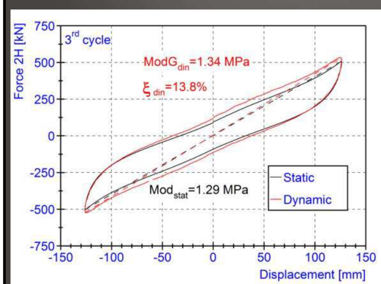
SILER Project
Development of rubber compounds

- Development of high damping compounds
- Tests on isolators diam. 500 mm for dynamic characterization



Tests at s.s. 100 %
on 2 isolators
SI-H 500/126
diam. 500 mm
total rubber height 126 mm

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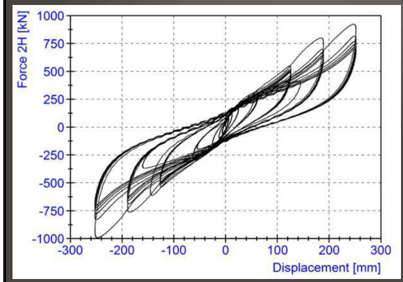
SILER Project
Development of rubber compounds

- Development of high damping compounds
- Tests on isolators diam. 500 mm for dynamic characterization



Dynamic tests (f=0.5 Hz) at increasing shear strain 5, 10, 20, 50, 100, **200 %** according to EN 15129 on 2 isolators SI-H 500/126 diam. 500 mm total rubber height 126 mm

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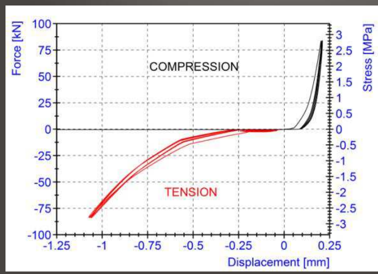
SILER Project
Development of rubber compounds

- Development of high damping compounds
- TENSION tests on isolator diam. 200 mm (IT 166 I)



Comparison of tension and compression behaviour

Higher non-linearity in tension than in compression

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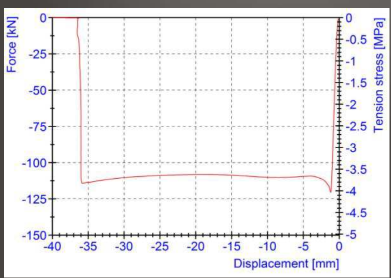
SILER Project
Development of rubber compounds

- Development of high damping compounds
- TENSION tests on isolator diam. 200 mm (IT 168 I)



Failure test in tension

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SILER Project
Development of rubber compounds

- Development of high damping compounds
- TENSION tests on isolator diam. 200 mm up to failure

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SILER Project
Development of rubber compounds

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SILER Project - High damping rubber bearings
Design of HDRB for MYRRHA

- Main input data:
  d=305 mm, ξ=10 % (response spectrum analysis)

80 isolators Type A
K_h=10 kN/mm
$N_{Ed, max}$ = 9856 kN
K_v=10000 kN/mm

259 isolators Type B
K_h=4 kN/mm
$N_{Ed, max}$ = 15083 kN
K_v=10000 kN/mm

- SI-H 1600/285 (Type A)
  diameter 1600 mm
  15 rubber layers t_r=19 mm
  total rubber thickness T_e=285 mm
  K_h=9.88 kN/mm
  K_v=8724 kN/mm
  $S_1 \approx 21$ / S_2 = 5.5
  $N_{Ed, max}$ = 15539 kN ($\sigma \approx 8$ MPa)
  s.s.=305/285= 107%

- SI-H 1050/290 (Type B)
  diameter 1050 mm
  29 rubber layers t_r=10 mm
  total rubber thickness T_e=290 mm
  K_h=4.18 kN/mm
  K_v=4229 kN/mm
  $S_1 \approx 26$ / S_2 = 3.6
  $N_{Ed, max}$ = 12442 kN ($\sigma \approx 15$ MPa)
  s.s.=305/290=105%

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SILER Project - High damping rubber bearings
Design of HDRB for ELSY

- Main input data:
  225 isolators (15 x 15 grid)
  K_h= 7.4 ÷ 8.3 kN/mm (T=1.8 ÷ 1.7 s)
  ξ=10 %
  d≈250 mm
  $N_{Ed, max}$= 25700 kN
  $N_{Ed, min}$ = -3570 kN (tension load)
- Final design: SI-H 1350/256
  d= 251 mm (including eccentricity, time history EC8 t3, FEMA model)
  $N_{Ed, max}$= 20400 kN ⇒ $\sigma \approx 15$ MPa
  $N_{Ed, min}$ = -1300 kN (tension load) ⇒ $\sigma \approx -1$ MPa
  In the structural model the tension vertical stiffness has been assumed equal to the compression vertical stiffness. Using a reduced vertical stiffness, the tension load is much lower.

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Task 4.2 - High damping rubber bearings
Design of HDRB for ELSY

- SI-H 1350/256
  diameter 1350 mm
  16 rubber layers t_r=16 mm
  total rubber thickness T_e=256 mm
  shear strain = 251/256 = 98 %
- selected as the prototype of HDRB to be manufactured and tested

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Task 4.3 – Lead rubber bearings
Design of LRB for MYRRHA

- Main input data:
  ξ=25 %

80 isolators Type A
K_h = 15 kN/mm
K_v = 15000 kN/mm
N_{Ed}= 20123 kN
d=216 mm

259 isolators Type B
K_h = 4.5 kN/mm
K_v = 4500 kN/mm
N_{Ed}= 11878 kN
d=207 mm

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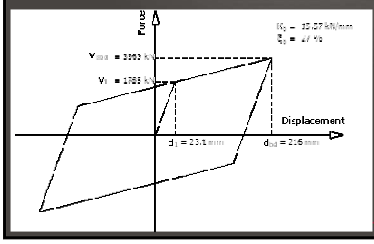
Task 4.3 – Lead rubber bearings
Design of LRB for MYRRHA

- LRB-LH 1350x1350/286-220q (type A)
  G=1.4 MPa
  K_h=15.57 kN/mm (at d=216 mm)
  ξ =27 % (at d=216 mm)
  K_v= 7706 kN/mm



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Conclusions

For application in nuclear power plants, it is very important to know the behaviour of the isolators beyond design conditions

- Consequently tests on **full scale** isolators of the SILER project will be carried out up to failure and in real dynamic conditions under 3D input

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