

BAB VI

KESIMPULAN DAN SARAN

6.1 Kesimpulan

Berdasarkan hasil pemodelan numerik dengan menggunakan perangkat lunak OpenSees, serta analisis terhadap respons struktur portal sederhana dengan dan tanpa sistem isolasi dasar, diperoleh beberapa kesimpulan sebagai berikut:

1. Model numerik Glass Fiber Reinforced Elastomeric Isolator (GFREI) berhasil dikembangkan di OpenSees dengan mengacu pada data eksperimen Tavio dan Wijaya (2020). Model menggunakan pendekatan elemen *elastomericBearingBoucWen* dan *zeroLength element*, serta mampu merepresentasikan perilaku histeretik GFREI dengan baik.
2. Validasi Grafik Histeretik
Hasil simulasi Grafik histeresis menunjukkan bentuk loop yang sebanding dengan hasil eksperimen. Dari perhitungan:
 - Kekakuan efektif (K_{eff}) hasil simulasi = 451,30 kN/m, sedangkan eksperimen = 499 kN/m, dengan Selisih sekitar 9,7%.
 - Rasio redaman (ξ_{eff}) hasil simulasi = 5,003%, sedangkan eksperimen = 4,577%, dengan selisih sekitar 9,30%
3. Simpangan struktur pada portal *fix-based* sebesar 12,5 mm untuk nilai maksimum dan 11,56 mm untuk nilai minimum, serta pada isolator based sebesar 4 mm untuk nilai maksimum dan minimum. Sedangkan simpangan relatif maksimum isolator berkisar pada 13 mm.
4. Grafik histeresis hasil analisis menunjukkan terbentuknya *loop* yang menggambarkan disipasi energi oleh isolator. Hal ini menguatkan peran isolator sebagai elemen peredam energi yang dapat meningkatkan daktilitas serta mengurangi risiko kerusakan pada struktur utama.

6.2 Saran

Berdasarkan temuan penelitian ini, beberapa saran yang dapat diberikan adalah sebagai berikut:

1. Perlu dilakukan kajian lebih lanjut dengan variasi parameter isolator (misalnya kekakuan, redaman, dan dimensi) untuk memperoleh konfigurasi yang paling optimal dalam menyeimbangkan reduksi gaya geser dan simpangan struktur.
2. Untuk pengembangan penelitian selanjutnya, analisis dapat diperluas dengan mempertimbangkan jenis gempa yang berbeda, baik gempa moderat maupun gempa dengan intensitas tinggi, guna menguji konsistensi kinerja isolator pada berbagai skenario beban.

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LAMPIRAN

Lampiran Program OpenSees Portal dengan Fix-Based

```
# =====  
# PORTAL 1 LANTAI – FIXED-BASE (Baseline)  
# Satuan: N, mm, s | ACC_ELC9.txt dalam mm/s^2  
# =====  
  
wipe  
model BasicBuilder -ndm 2 -ndf 3  
  
# ----- PARAMETER UMUM -----  
set g 9810.0  
set dt 0.005  
set tFinal 40.0  
set scaleAccel 1.50 ;# skala percepatan El Centro (mm/s^2)  
set zetaMass 0.02 ;# damping proporsional massa ~2%  
  
# ----- MATERIAL -----  
set fc -35.0  
set eps -0.004  
set fcu [expr 0.1*$fc]  
set epsu -0.014  
set fy 420.0  
set E0 200000.0  
set Ec 36000.0  
set bSteel 0.01  
  
uniaxialMaterial Concrete01 1 $fc $eps $fcu $epsu  
uniaxialMaterial Steel01 2 $fy $E0 $bSteel  
  
# ----- GEOMETRI RANGKA -----  
set H 4000.0  
set L 4000.0  
  
set bcol 500.0  
set hcol 500.0  
set Acol [expr $bcol*$hcol]  
set Icol [expr (1.0/12.0)*$bcol*pow($hcol,3)]
```

```

set bbeam 250.0
set hbeam 500.0
set Abeam [expr $bbeam*$hbeam]
set Ibeam [expr (1.0/12.0)*$bbeam*pow($hbeam,3)]

geomTransf Linear 1

# ----- NODES -----
node 1 0 0
node 2 $L 0
node 3 0 $H
node 4 $L $H

fix 1 1 1 1
fix 2 1 1 1

# ----- ELEMEN -----
element elasticBeamColumn 1 1 3 $Acol $Ec $Icol 1
element elasticBeamColumn 2 2 4 $Acol $Ec $Icol 1
element elasticBeamColumn 3 3 4 $Abeam $Ec $Ibeam 1

# ----- BEBAN GRAVITASI & MASSA -----
# Berat total superstruktur (sesuai diskusi): 80 kN
set Wtotal_kN 80.0
# massa efektif di node lantai
set m_each [expr ($Wtotal_kN*1000.0/$g)/2.0]
mass 3 $m_each 0.0 0.0
mass 4 $m_each 0.0 0.0

pattern Plain 10 Linear {
    load 3 0.0 -1.0 0.0
    load 4 0.0 -1.0 0.0
}
loadConst -time 0.0

# ----- GEMPA INPUT -----
timeSeries Path 1 -dt $dt -filePath ACC_ELC9.txt -factor $scaleAccel
pattern UniformExcitation 1 1 -accel 1 ;# arah X

# ----- RAYLEIGH DAMPING -----
# mass proportional only (≈ 2% pada mode rendah)
set T1 0.08
set w1 [expr 2.0*3.14159265/$T1]
set a0 [expr 2.0*$zetaMass*$w1]
rayleigh $a0 0.0 0.0 0.0

# ----- RECORDER -----
recorder Node -file fix_disp.out -time -node 3 4 -dof 1 disp
recorder Node -file fix_RL.out -time -node 1 -dof 1 reaction
recorder Node -file fix_RR.out -time -node 2 -dof 1 reaction

# ----- ANALISIS -----
constraints Transformation
numberer RCM
system UmfPack
integrator Newmark 0.5 0.25

test NormDispIncr 1.0e-6 40 1
algorithm Newton
analysis Transient

```

```

set t 0.0
while {$t < $tFinal} {
  set ok [analyze 1 $dt]
  if {$ok != 0} {
    algorithm KrylovNewton
    test NormDispIncr 1.0e-5 120 1
    set ok [analyze 1 $dt]
    if {$ok != 0} {
      algorithm NewtonLineSearch 0.8
      test NormDispIncr 5.0e-5 200 1
      set ok [analyze 1 $dt]
      if {$ok != 0} {
        algorithm ModifiedNewton -initial
        test NormDispIncr 1.0e-4 300 1
        analyze 1 $dt
      }
    }
    algorithm Newton
    test NormDispIncr 1.0e-6 40 1
  }
  set t [getTime]
}
puts "Selesai: FIXED-BASE TANPA ISOLATOR| W=${Wtotal_kN} kN, scaleAccel=$scaleAccel"
wipe

```

Lampiran Program OpenSees Portal dengan Isolator-Based

```
# =====
# PORTAL 1 LANTAI – BASE-ISOLATED (GFREI Bouc-Wen, Type A)
# Satuan: N, mm, s | ACC_ELC9.txt dalam mm/s^2
# =====

wipe
model BasicBuilder -ndm 2 -ndf 3

# ----- Umum -----
set g      9810.0
set dt     0.005
set tFinal 40.0
set zetaMass 0.02
set scaleAccel 1.0

# ----- Material rangka (elastik) -----
set Ec 36000.0
geomTransf Linear 1

# ----- Geometri -----
set H 4000.0
set L 4000.0
set bcol 500.0; set hcol 500.0
set Acol [expr $bcol*$hcol]
set Icol [expr (1.0/12.0)*$bcol*pow($hcol,3)]
set bbeam 250.0; set hbeam 500.0
set Abeam [expr $bbeam*$hbeam]
set Ibeam [expr (1.0/12.0)*$bbeam*pow($hbeam,3)]

# ----- Isolator GFREI (Type A) -----
# D=200 mm, 14 lapis @10 mm -> t_total=140 mm
set Diam 200.0
set Aiso [expr 3.14159265*pow($Diam/2.0,2.0)]
set Nrubber 14
set tR 10.0
set t_total [expr $Nrubber*$tR]

# >>> PERBAIKAN UNIT PALING PENTING <<<
# 1 MPa = 1 N/mm^2 (JANGAN dikali 1000)
set G_MPa 0.40 ;# modulus geser efektif (lunak)
set G $G_MPa ;# N/mm^2
set k0_one [expr $G*$Aiso/$t_total] ;# N/mm per isolator (~90 kN/m)

# Bouc-Wen lebih "lunak" + redaman cukup
set alpha 0.05 ;# post-yield stiffness ratio (k_post = alpha*k0)
set nBW 2.0
set gamBW 0.5
set betBW 0.5
set Ao 1.0
set dA 0.0
set dNu 0.0
set dEta 0.0
uniaxialMaterial BoucWen 301 $alpha $k0_one $nBW $gamBW $betBW $Ao $dA $dNu $dEta

set c_visc 350.0
uniaxialMaterial Viscous 302 $c_visc 1.0
uniaxialMaterial Parallel 300 301 302

set kVert 1.0e9
uniaxialMaterial Elastic 303 $kVert
```

```

# ----- Nodes -----
# Base fix
node 21 0 0
node 22 $L 0
fix 21 1 1 1
fix 22 1 1 1

# Titik bawah isolator (coincident base)
node 11 0 0
node 12 $L 0

# Titik atas isolator (pondasi kolom)
node 1 0 $t_total
node 2 $L $t_total

# Titik balok-kolom (lantai)
node 3 0 [expr $t_total + $H]
node 4 $L [expr $t_total + $H]

# ----- Elemen rangka -----
element elasticBeamColumn 1 1 3 $Acol $Ec $Icol 1
element elasticBeamColumn 2 2 4 $Acol $Ec $Icol 1
element elasticBeamColumn 3 3 4 $Abeam $Ec $Ibeam 1

# ----- Elemen isolator -----
element zeroLength 4 21 11 -mat 300 -dir 1
element zeroLength 5 22 12 -mat 300 -dir 1
element zeroLength 6 21 11 -mat 303 -dir 2
element zeroLength 7 22 12 -mat 303 -dir 2

# Rigid link ke atas isolator
rigidlink beam 11 1
rigidlink beam 12 2

```

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