Rotational Motions Extracted from Delaney Park Downhole Array in Anchorage, Alaska

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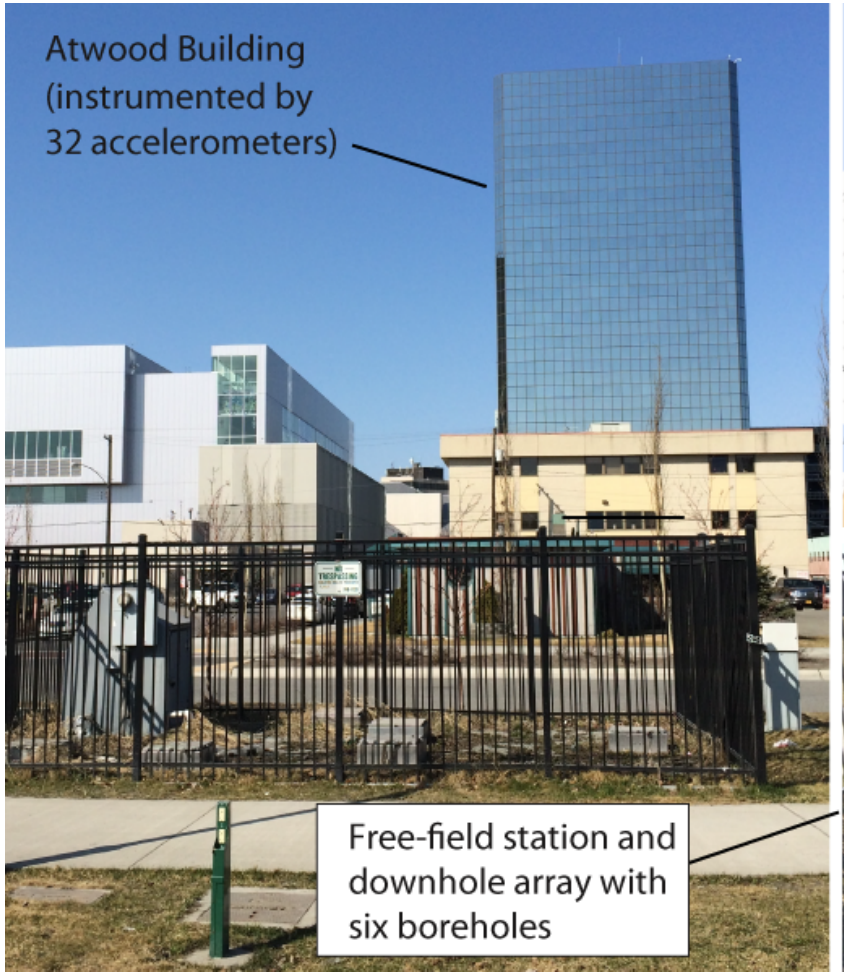
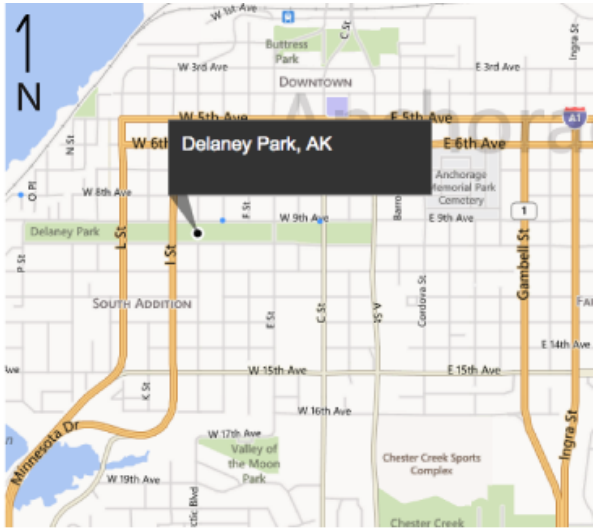
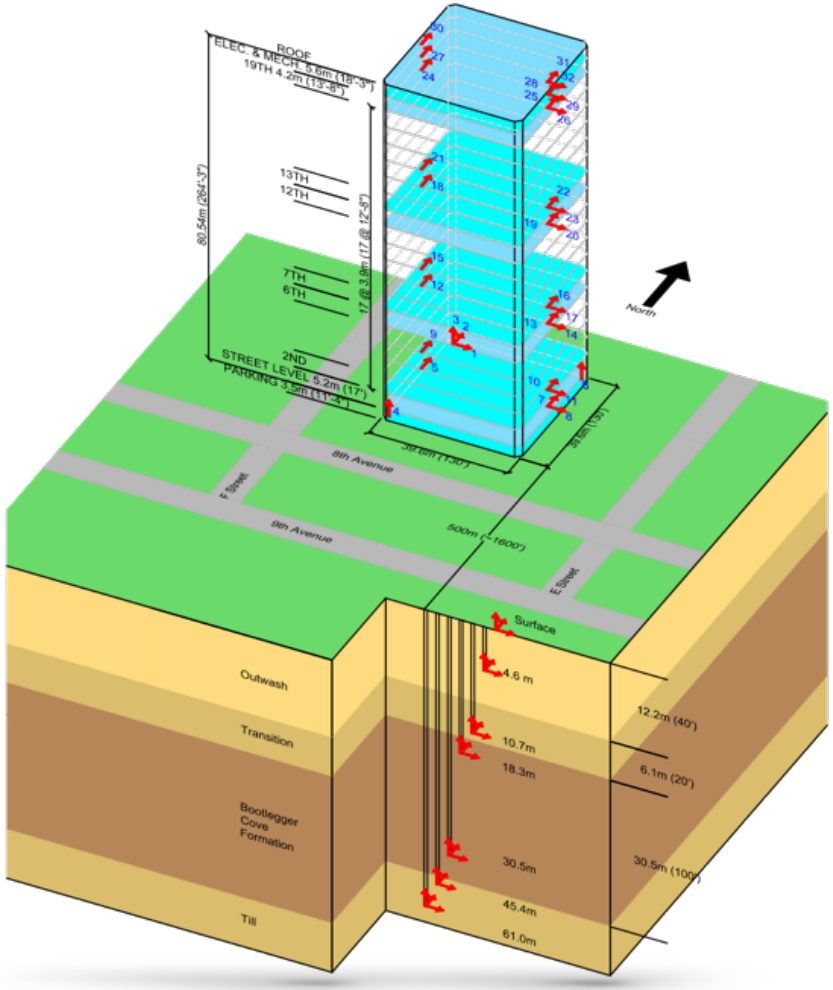
Delaney Park Geotechnical (DPK) Array



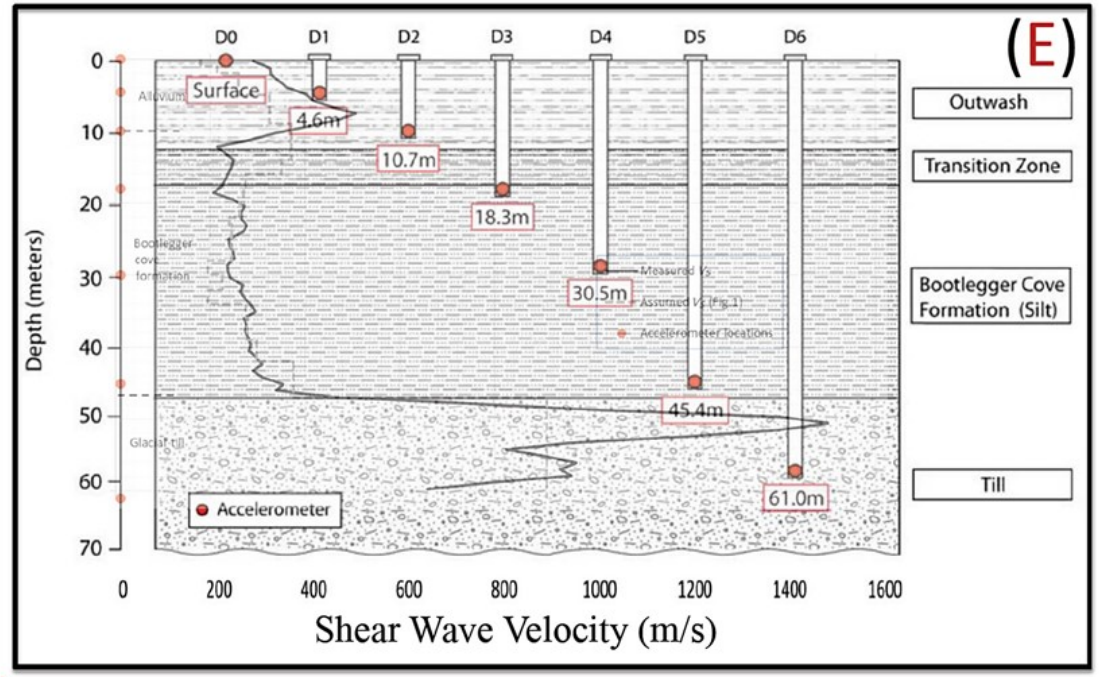


- DPK array is located at north-west downtown Anchorage.
- The array was installed in 2003 in a collaboration between UAA, USGS, NSF and UC Santa Barbara.
- It is now maintained jointly by the USGS and UC Santa Barbara.

Instrumentation & Geology



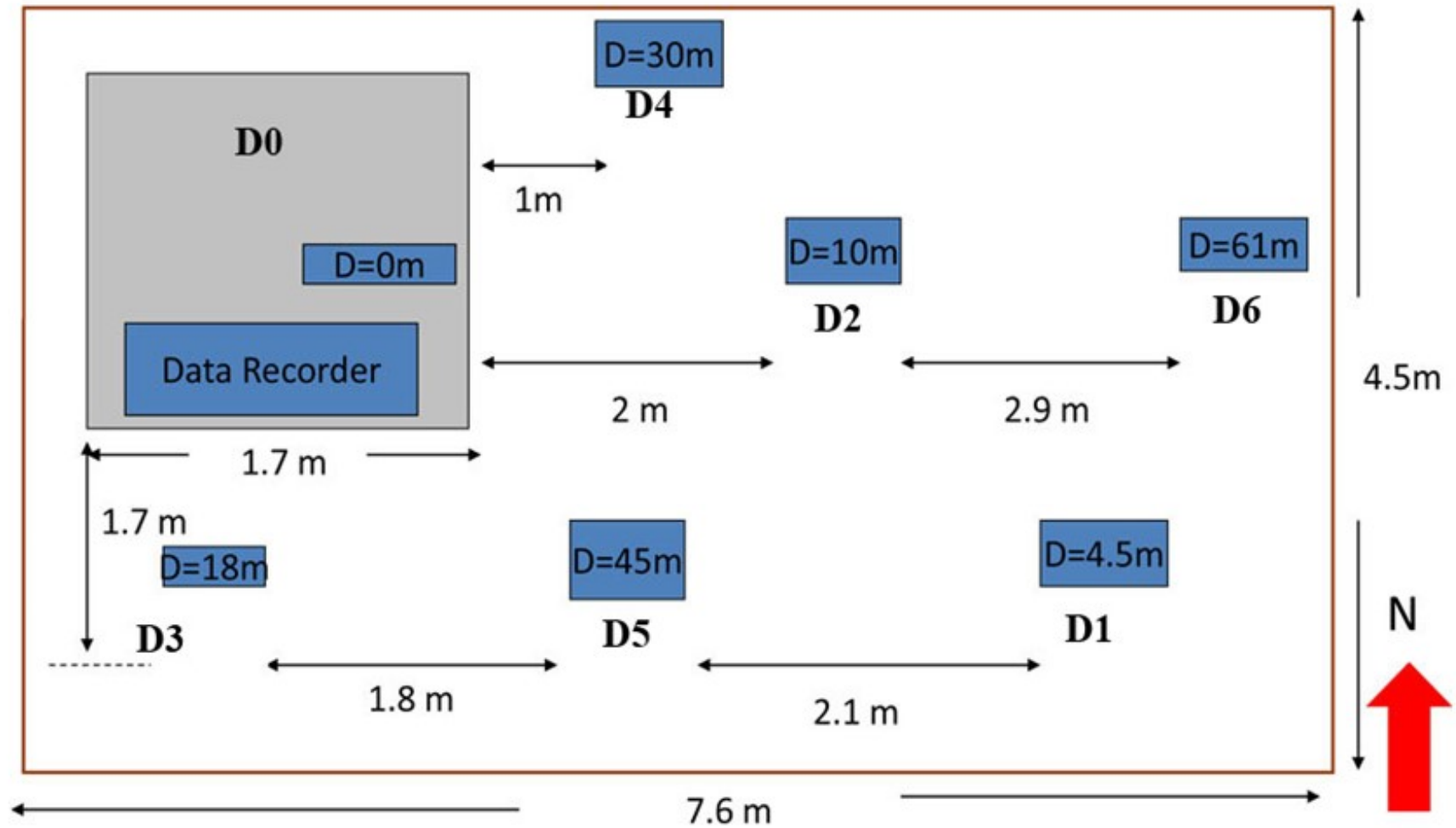
Cross-section and S-wave Velocity

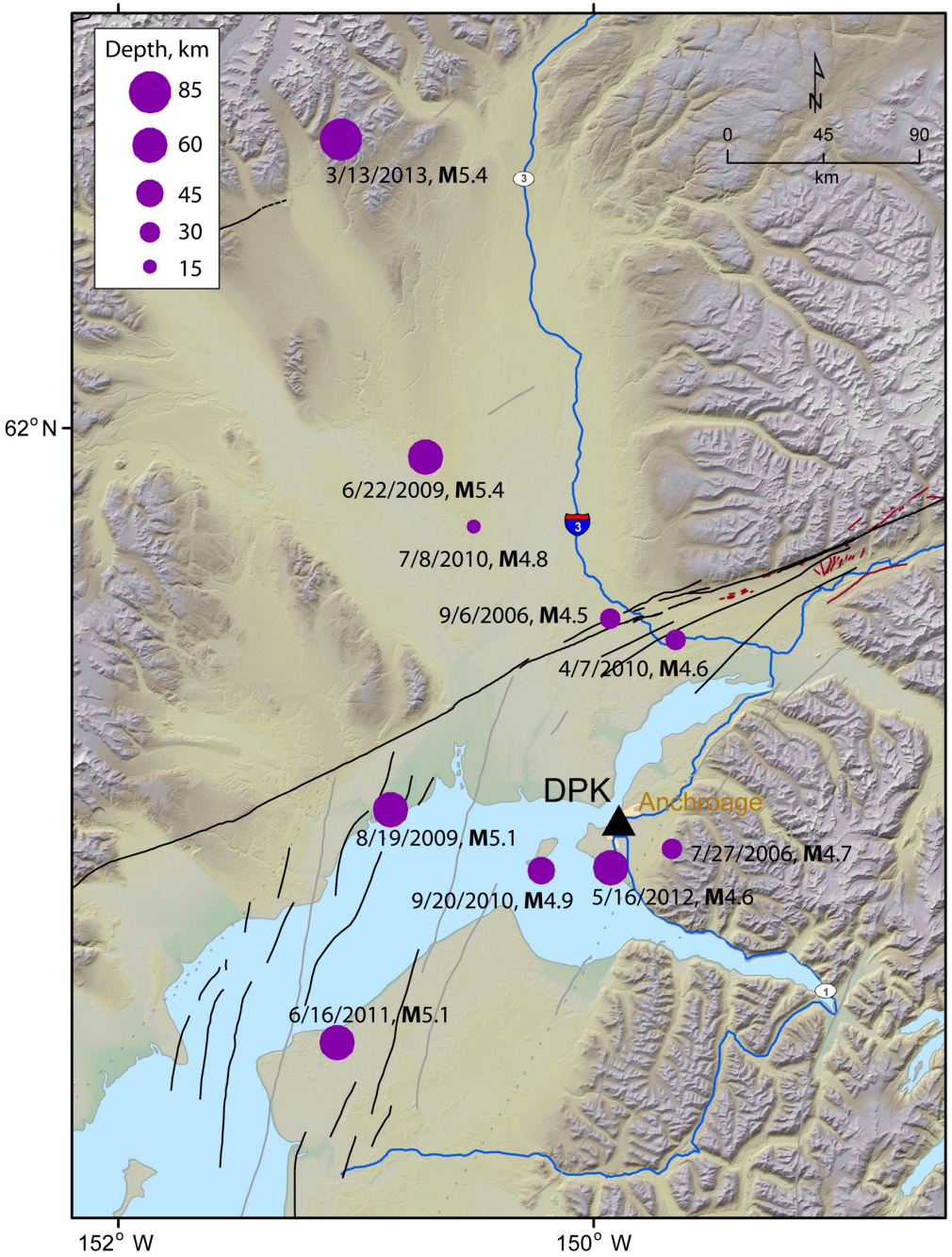


- Ground motions are measured at the surface and at six levels below the surface using borehole accelerometers.

- Accelerometers record motions in the glacial outwash sediments near the surface, the clays of the bootlegger cove formation, and at its deepest into the glacial till.

Schematic Plan of the Delaney Park Downhole Array



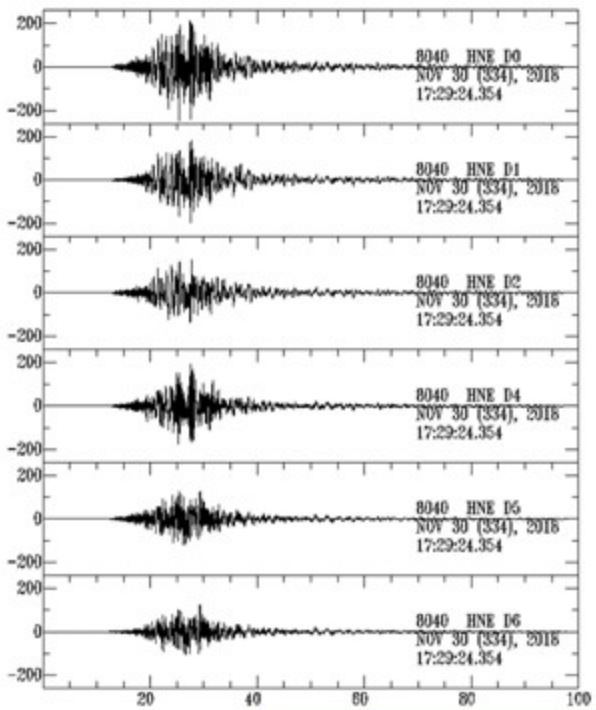


Earthquake Recordings

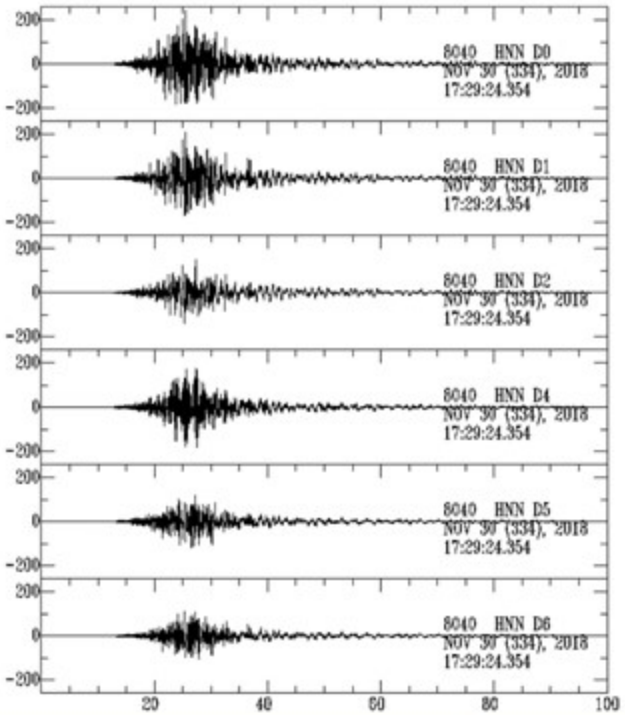
DPK Array recorded the **M**7 November 30, 2018 Anchorage Alaska Earthquake (epi dist=14.3 km, Depth=40.9 km) and a series of aftershocks including the **M**5.7, **M**4.8 and other smaller ones.

Delaney Array Recordings of November 30, 2018
M7.0 Anchorage Earthquake

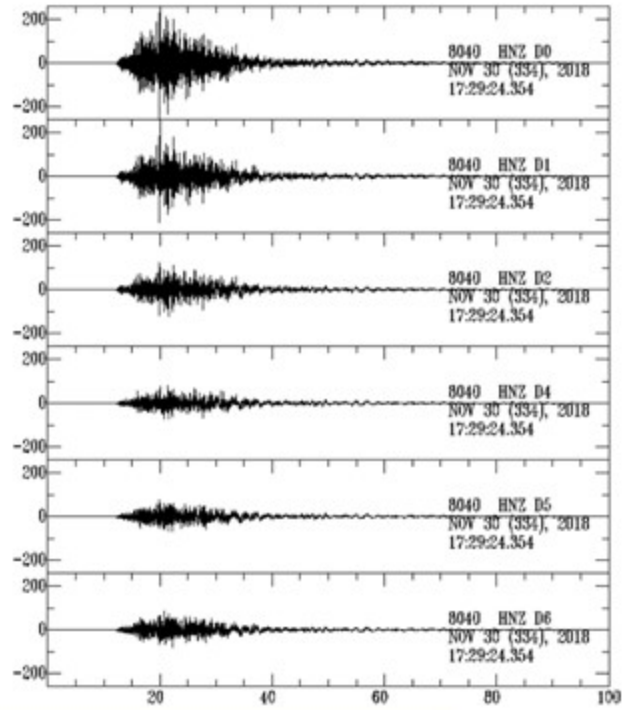
E-W



N-S

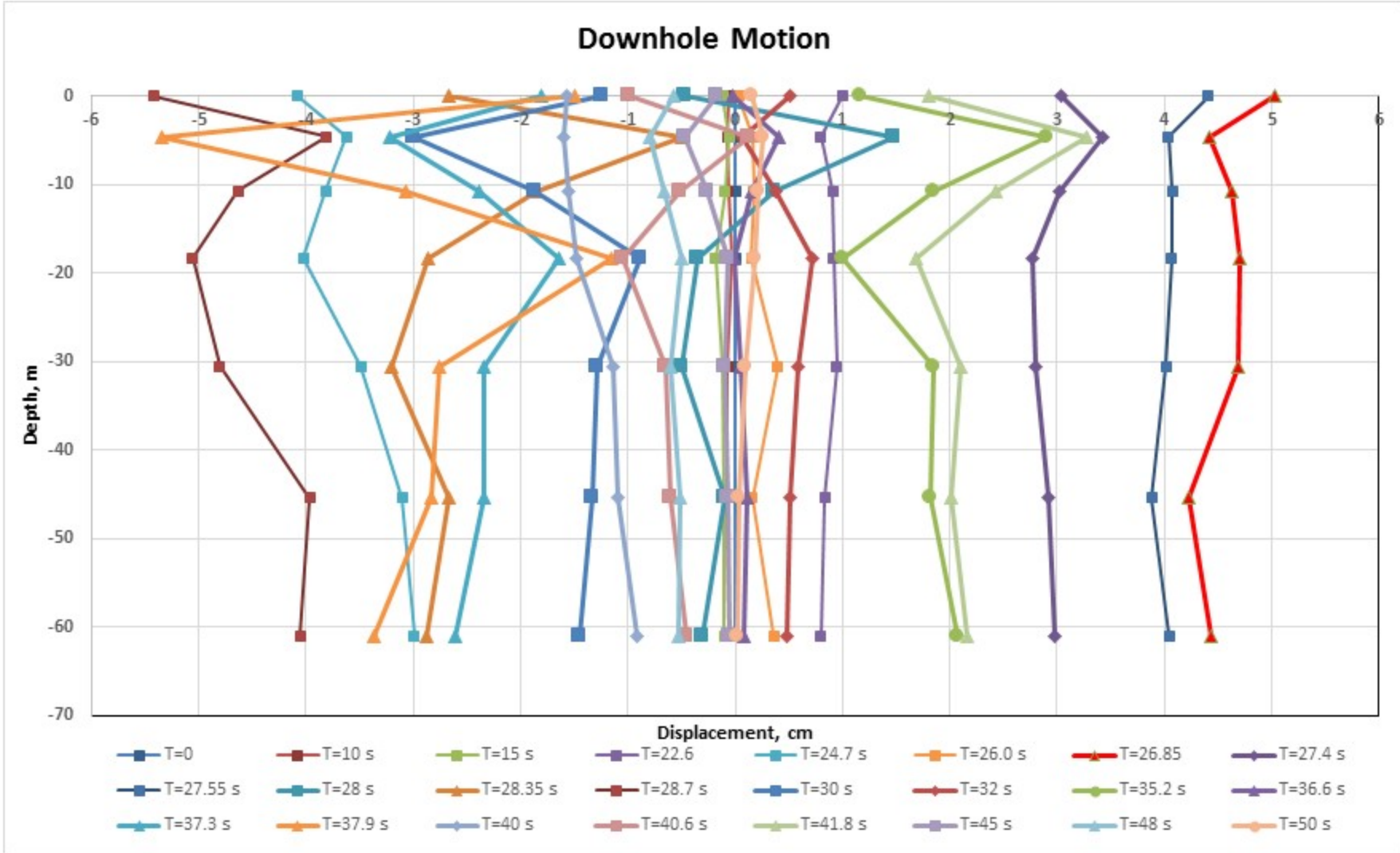


Vertical

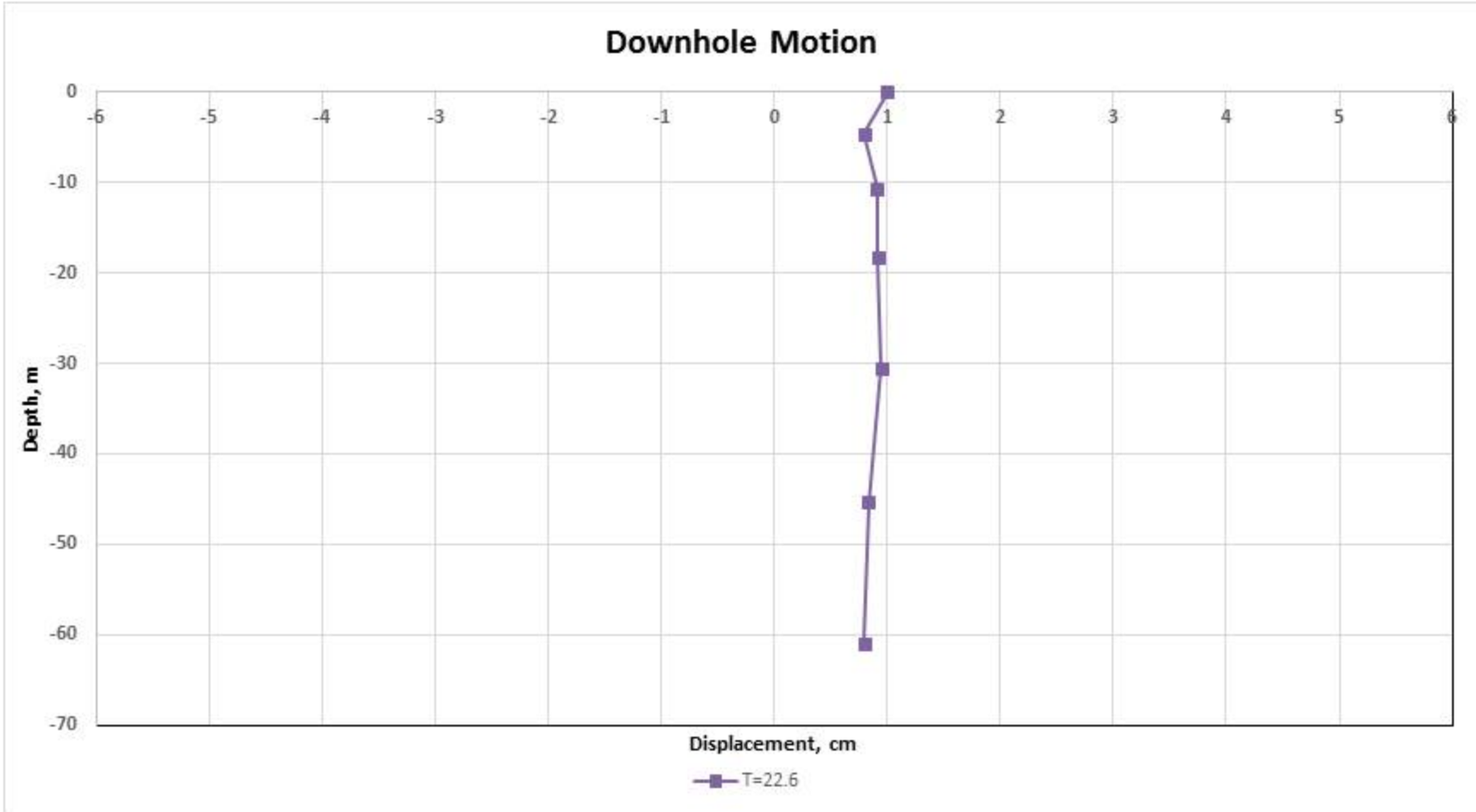


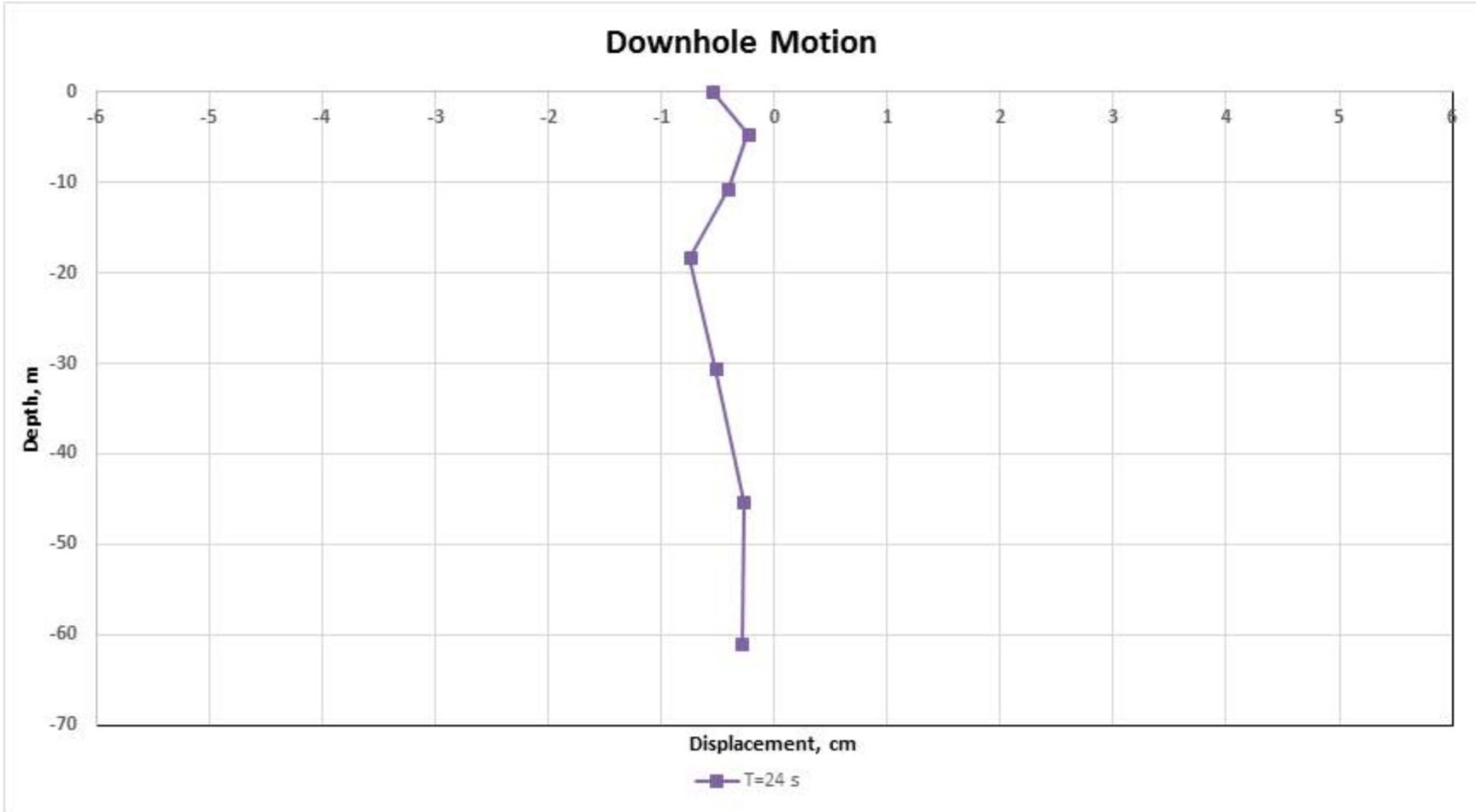
	D0			D1		
	Acceleration cm/s/s	Velocity Cm/s	Displacement cm	Acceleration cm/s/s	Velocity cm/s	Displacement cm
HNN	245.6	15.95	5.43	208.76	14.76	5.35
HNE	247.3	24.64	9.88	195.87	**25.65**	**10.52**
HNZ	**294.1**	7.64	2.73	212.27	7.26	4.19

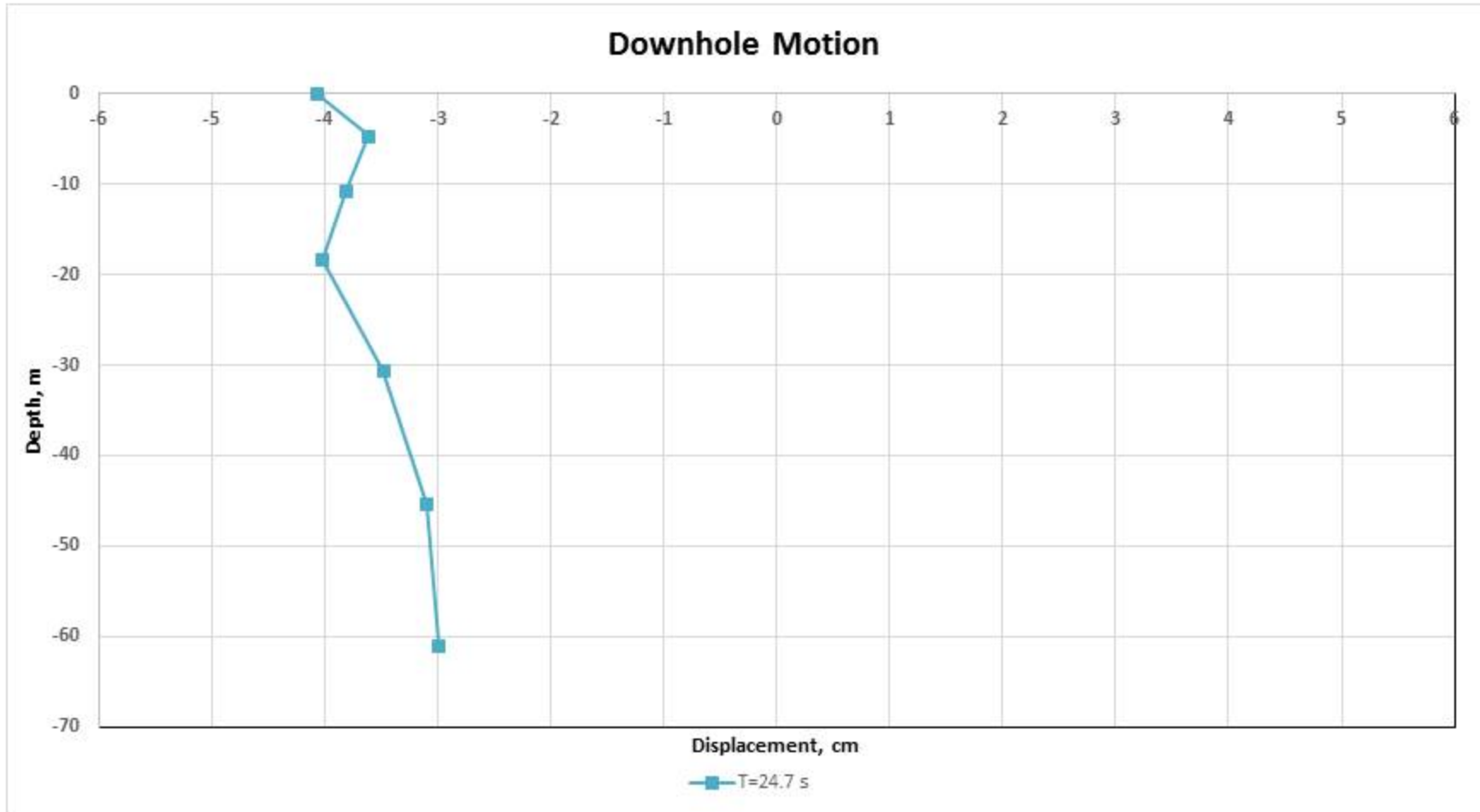
Displacements in Downhole

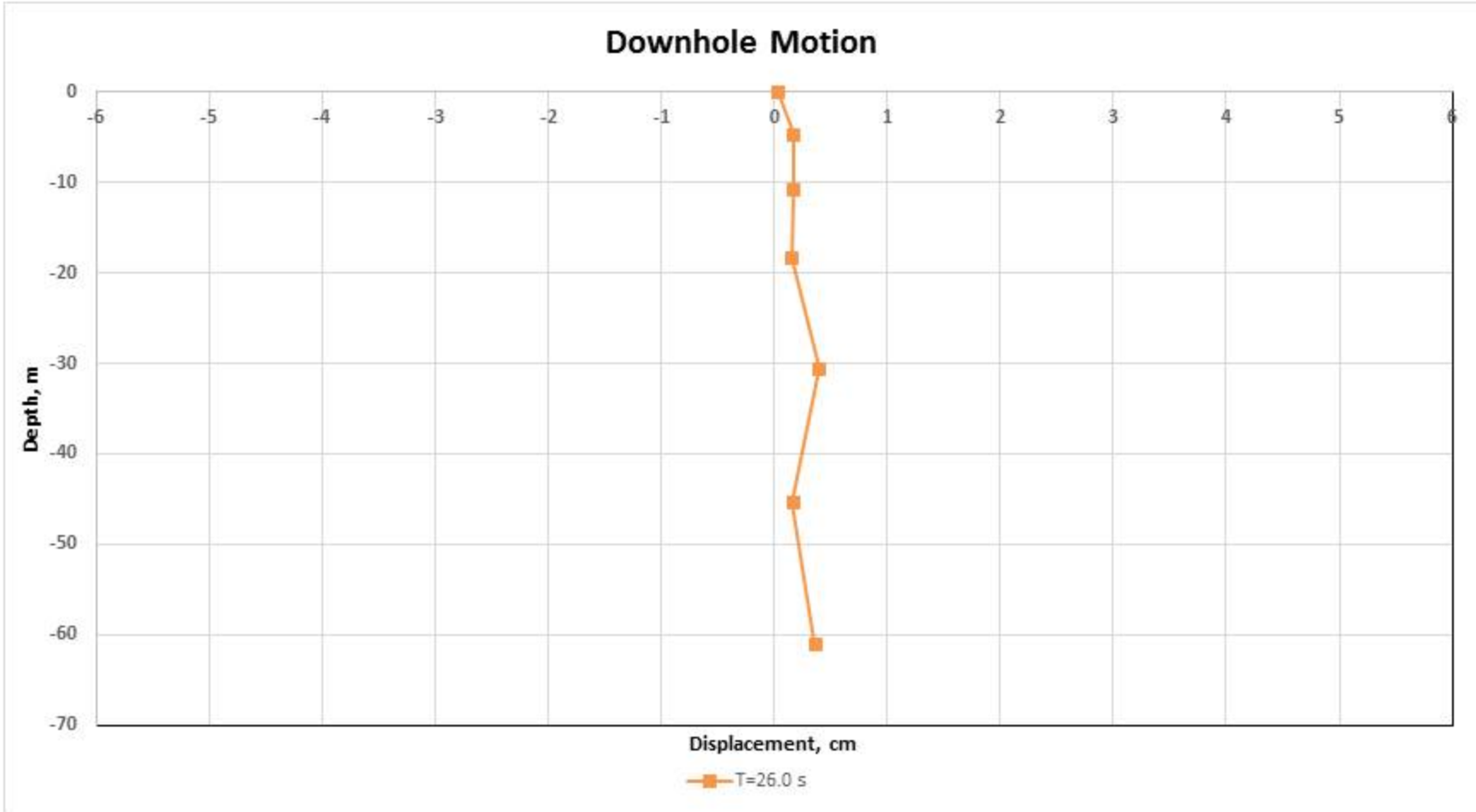


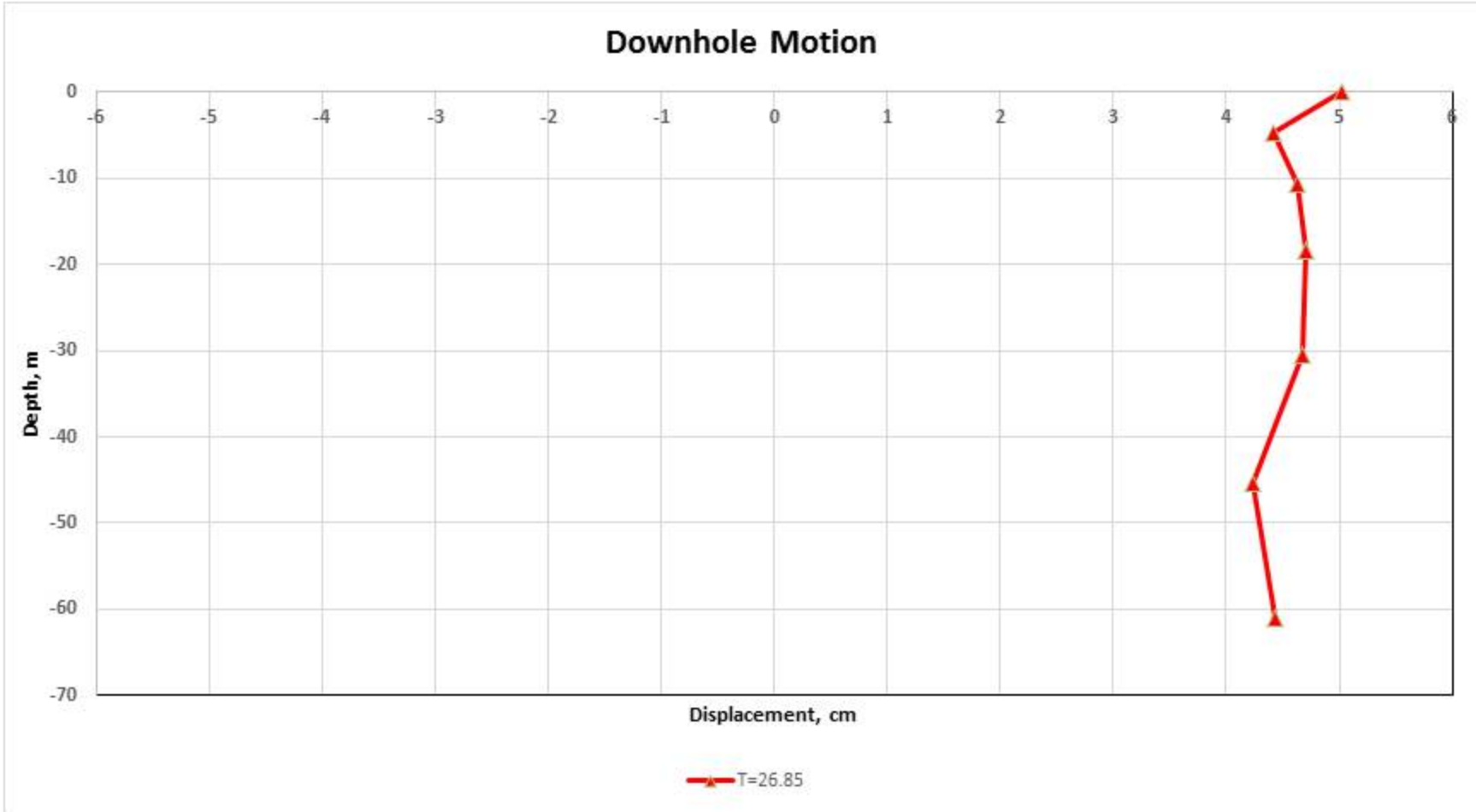
Downhole Displacement

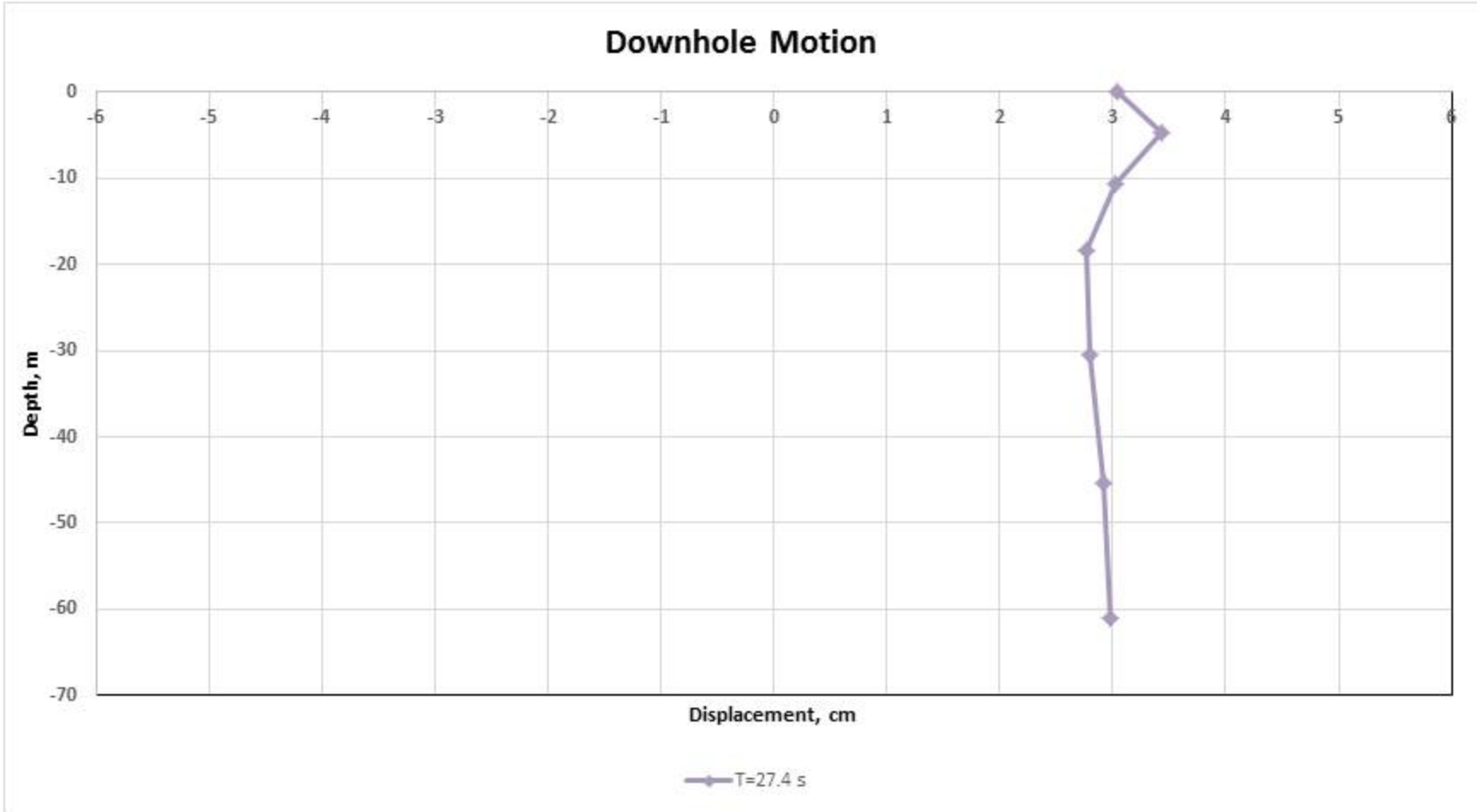

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=22.6

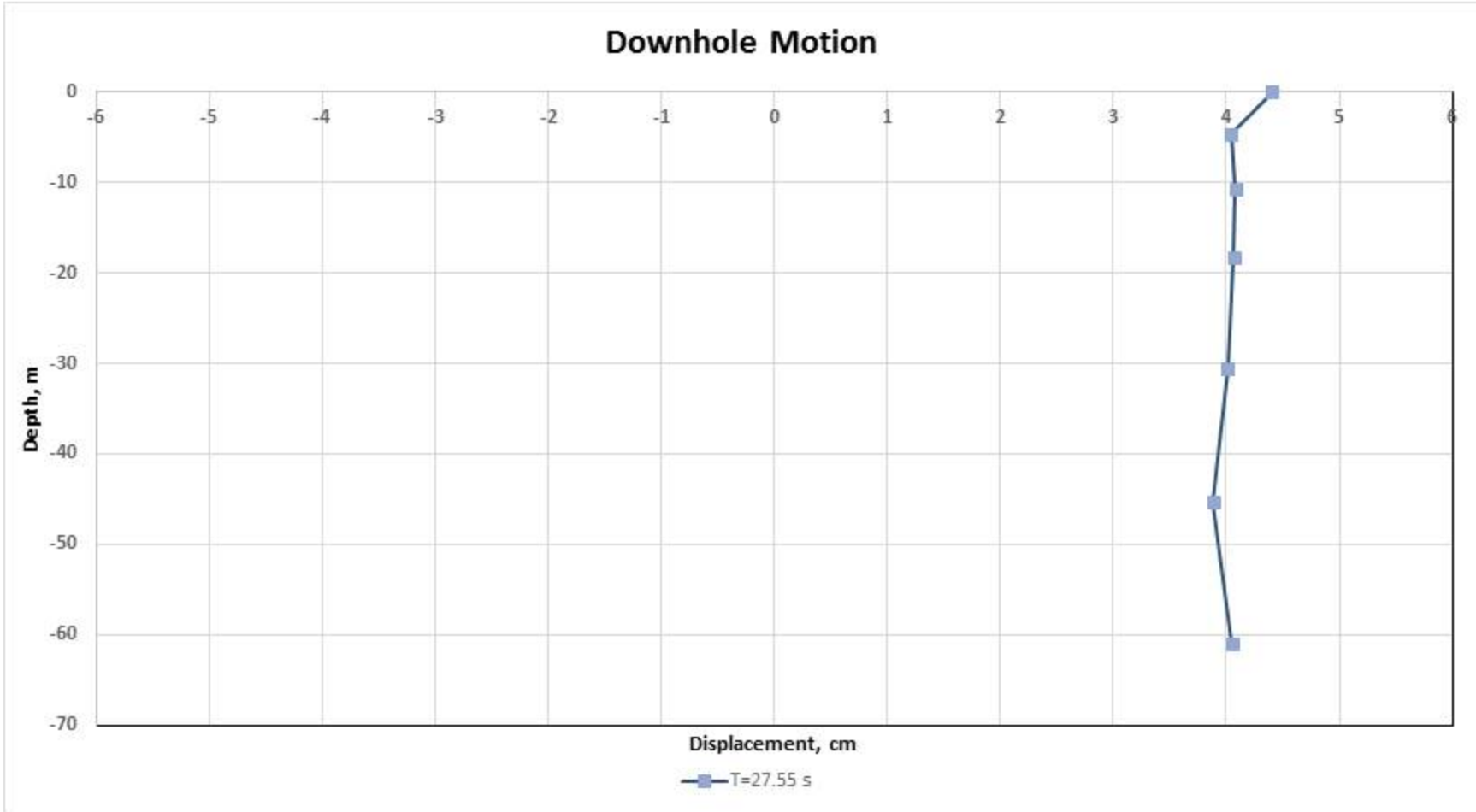

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=24 s

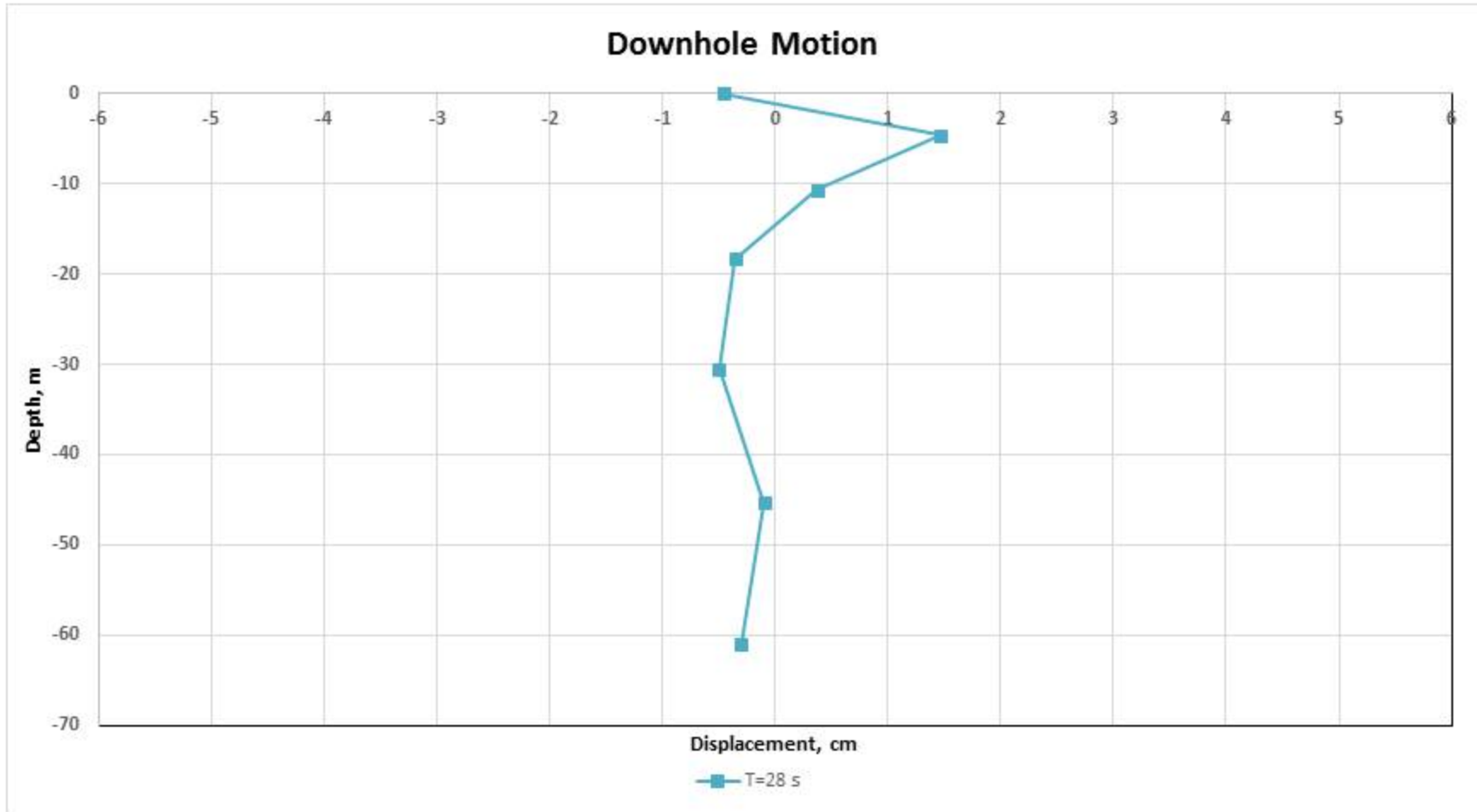

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=24.7 s

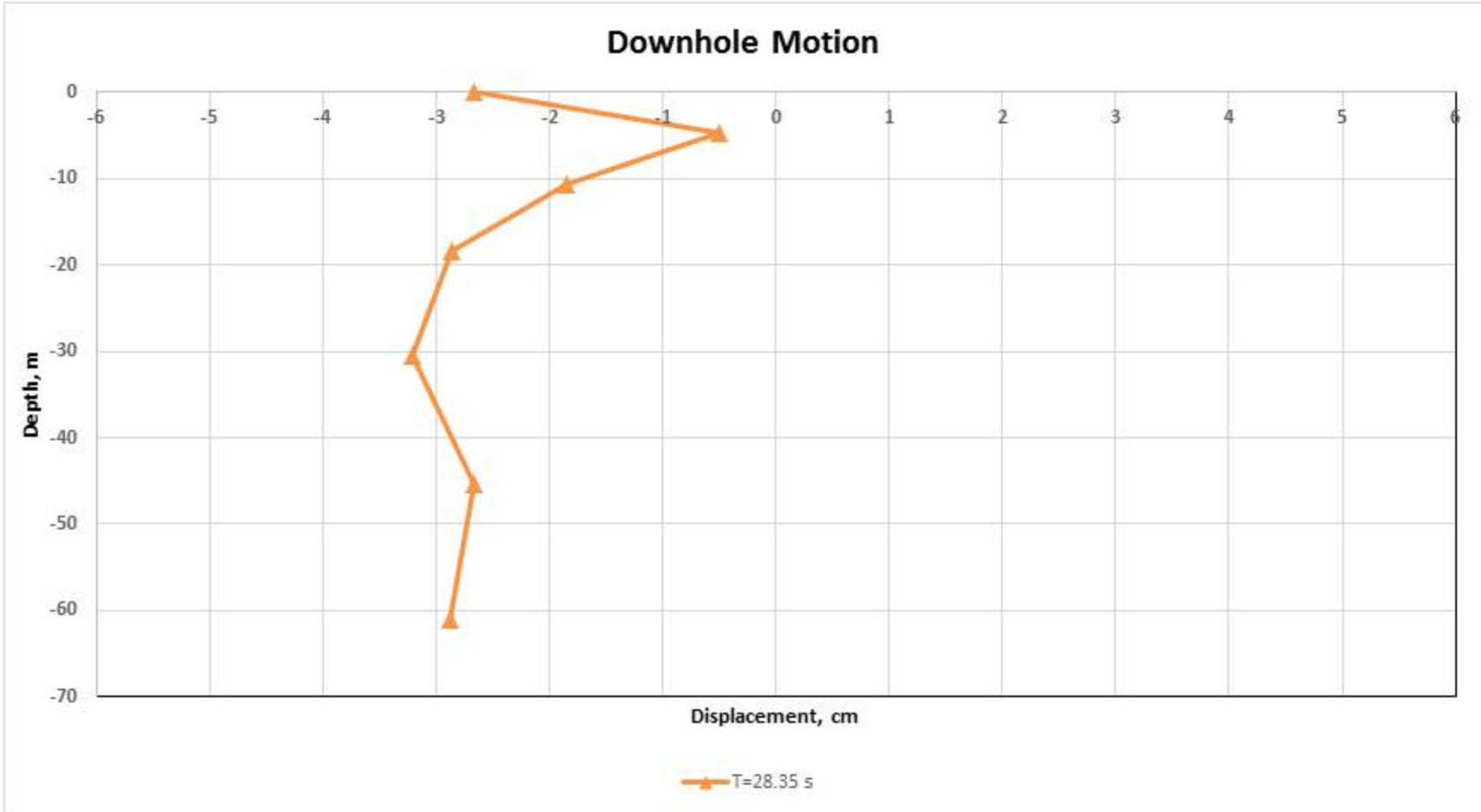

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=26.0 s

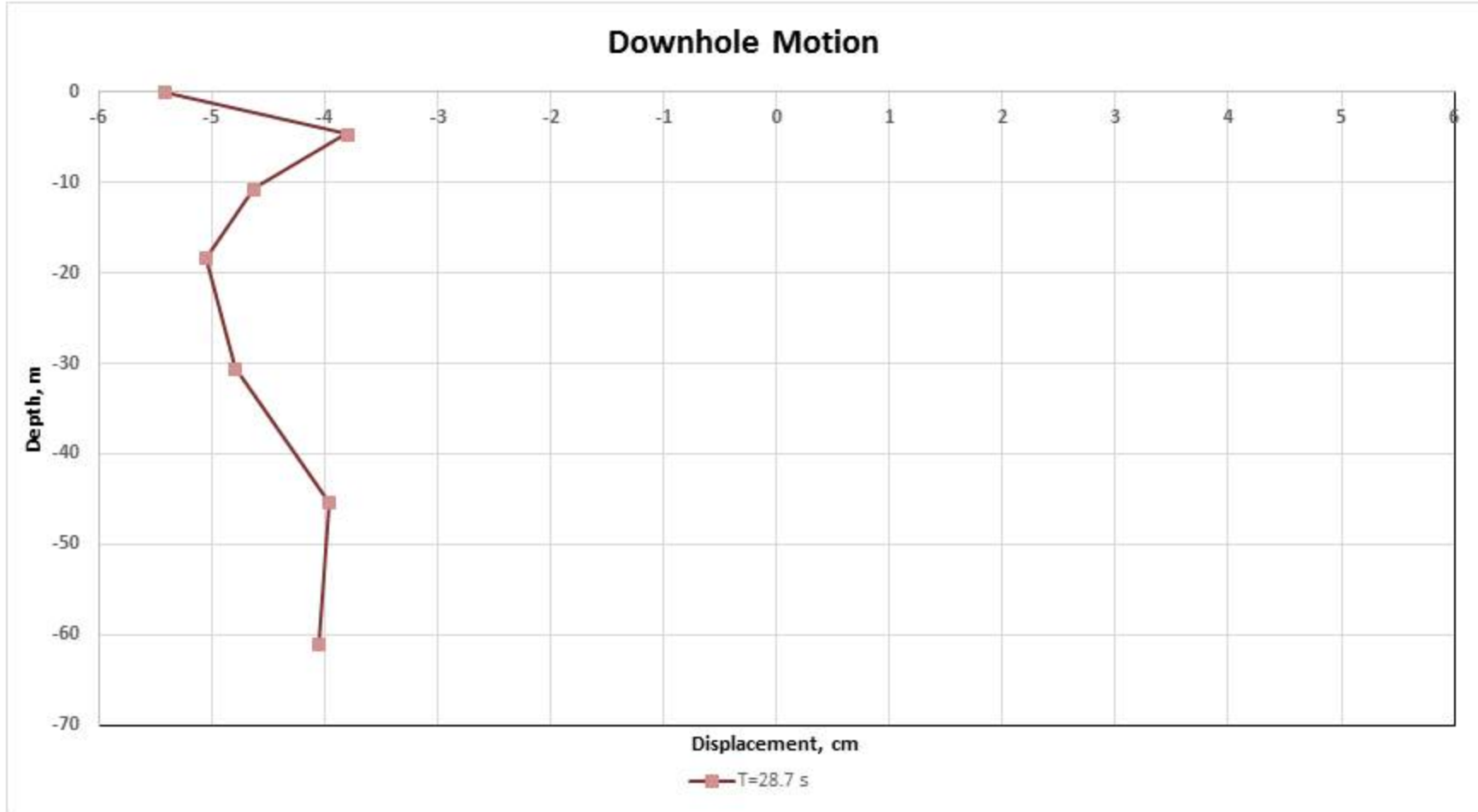

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=26.85

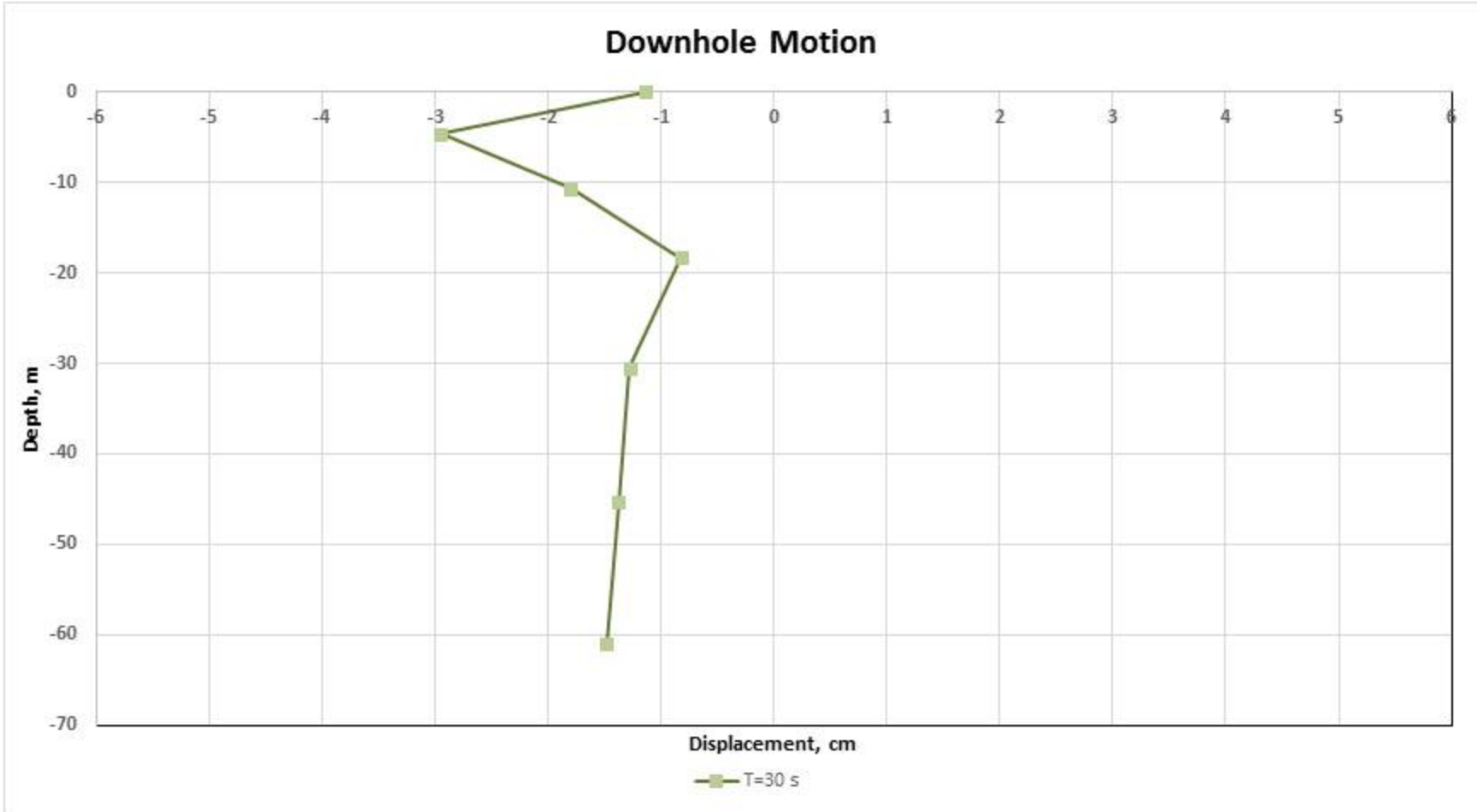

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=27.4 s

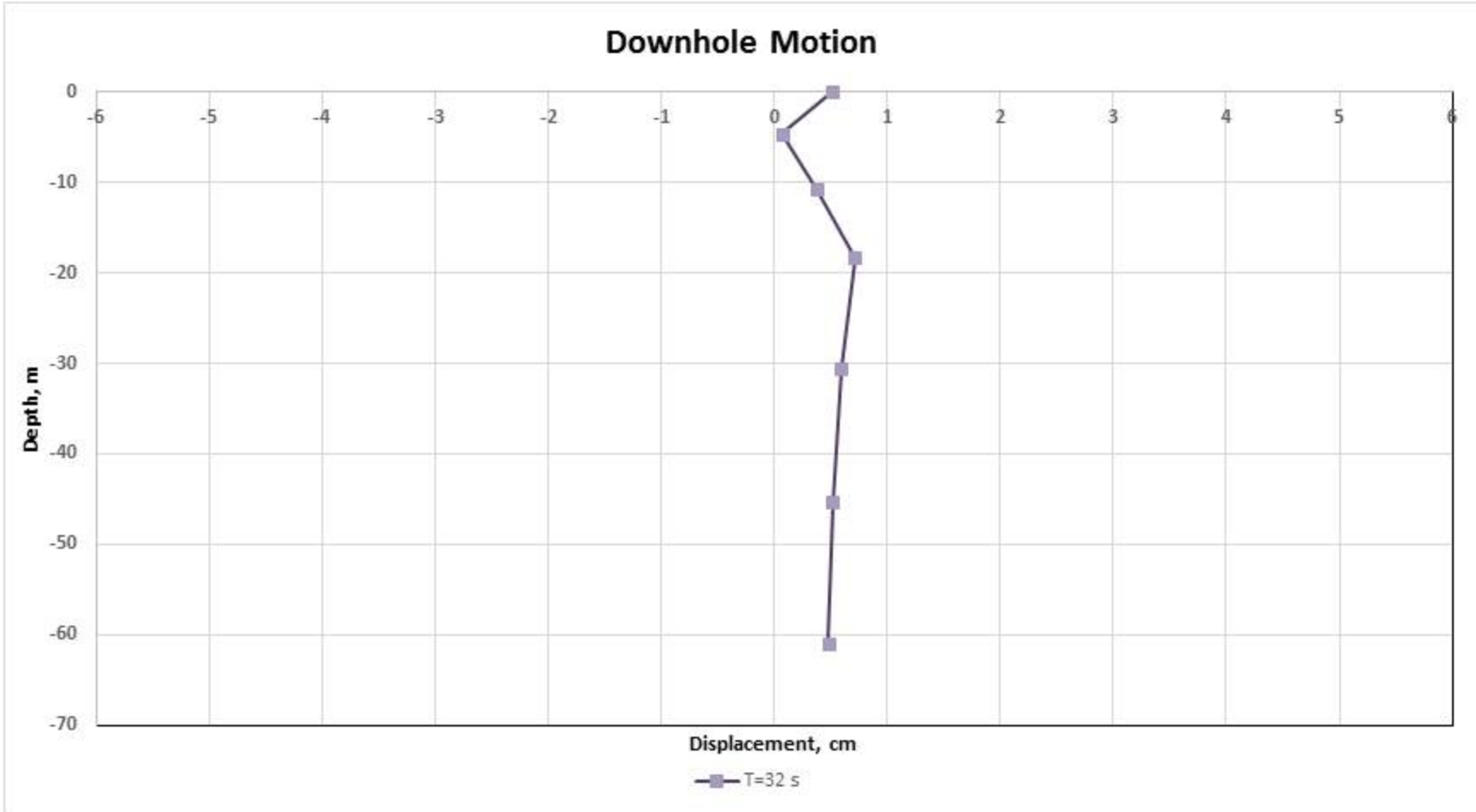

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=27.55 s

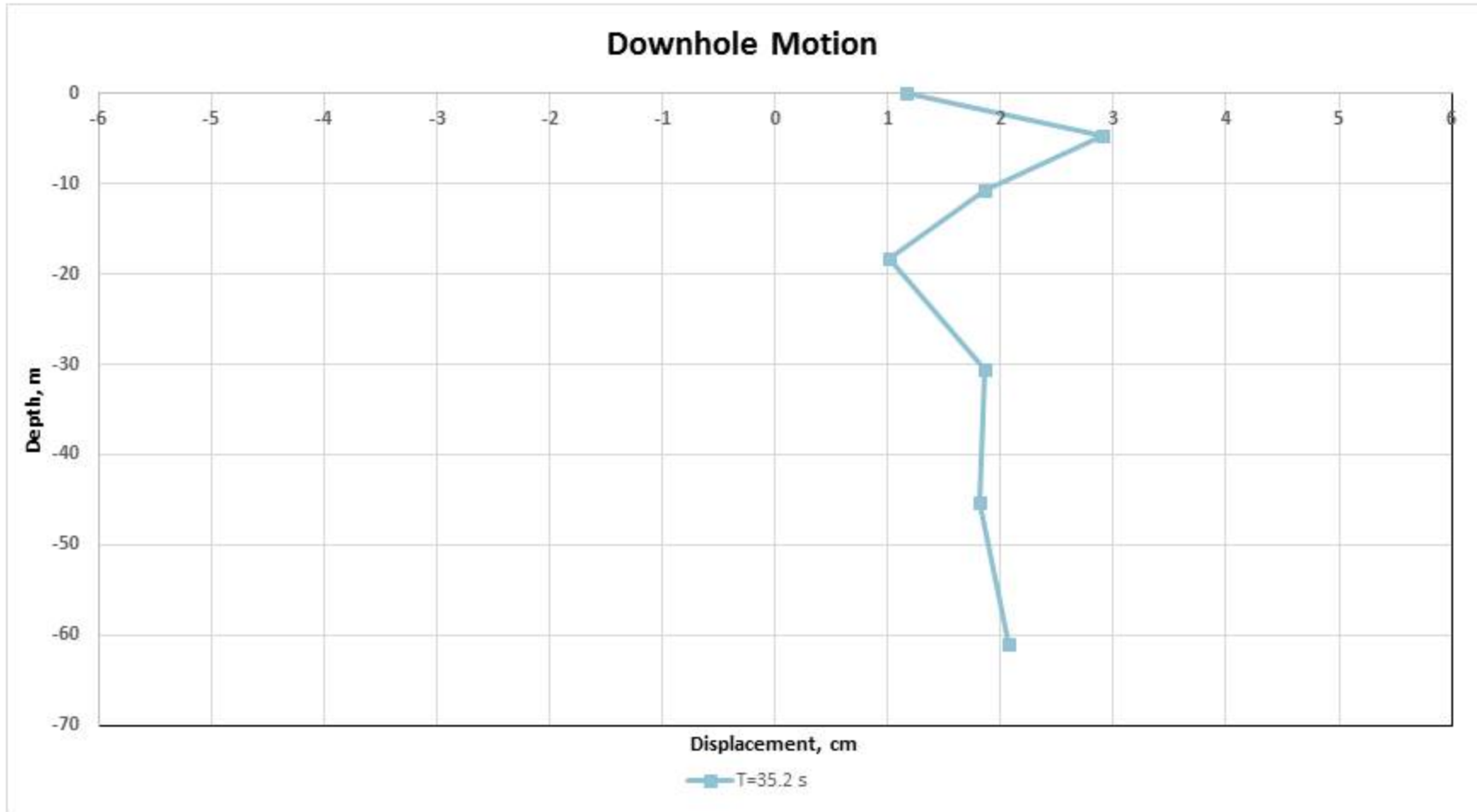

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=28 s

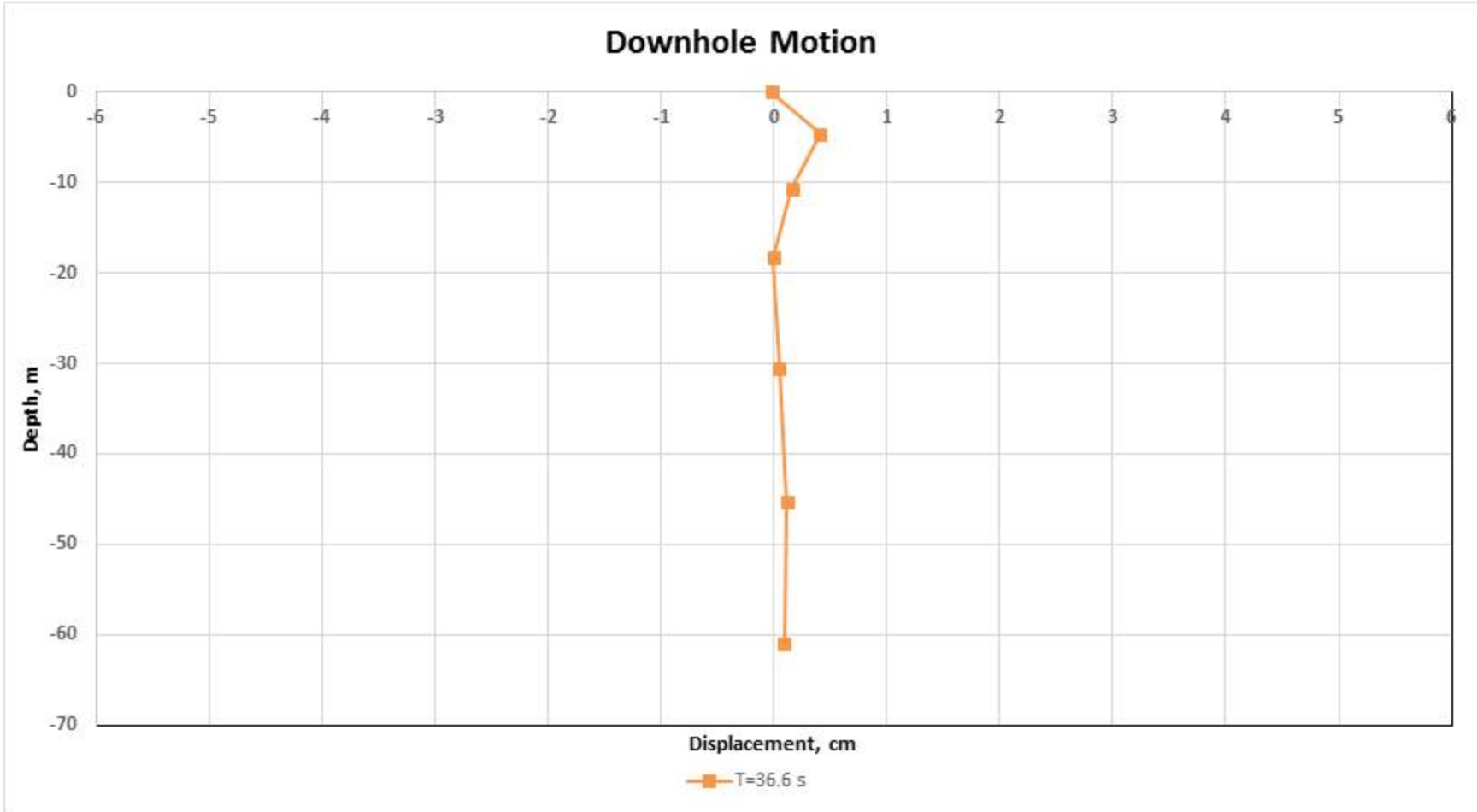

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=28.35 s

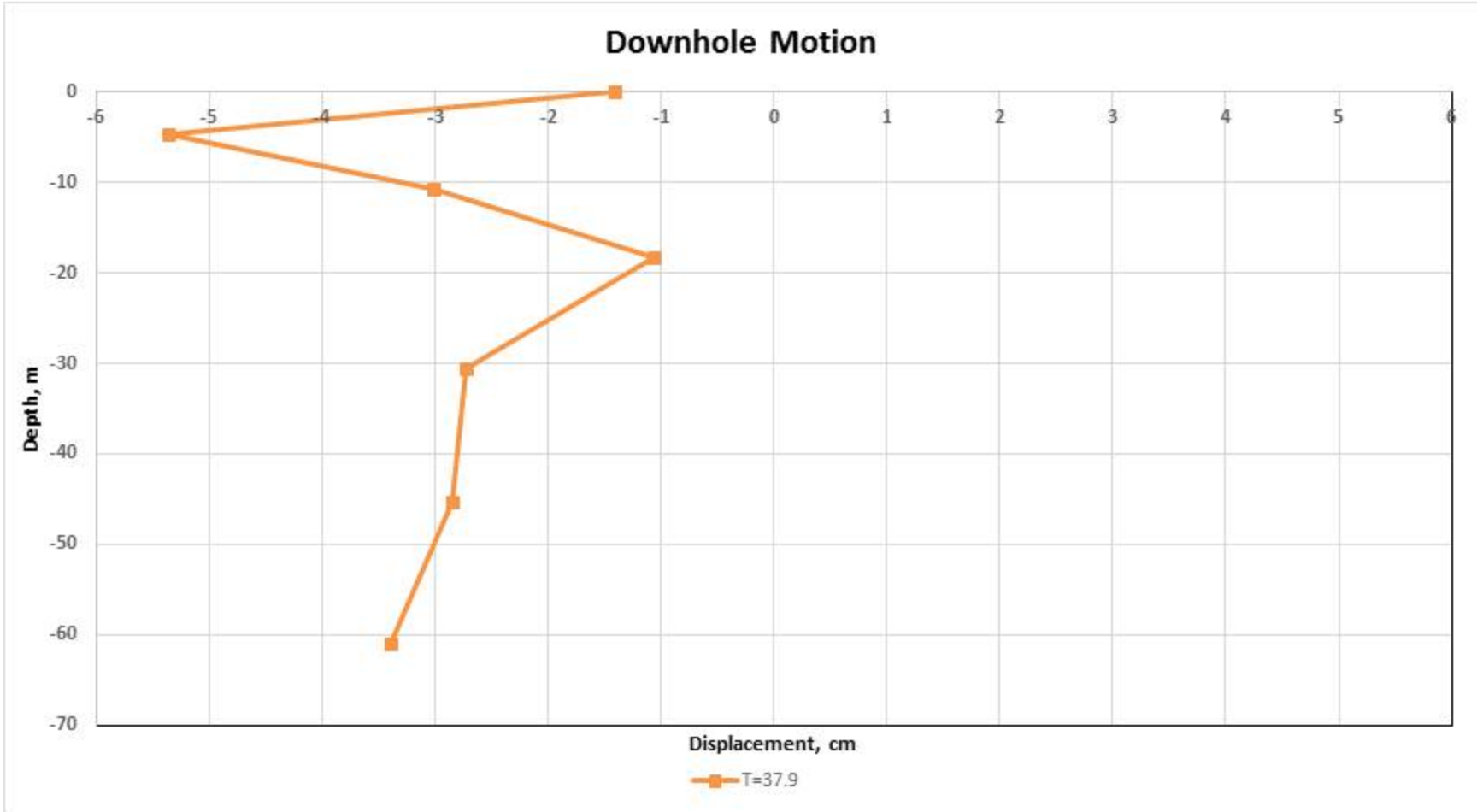

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=28.7 s

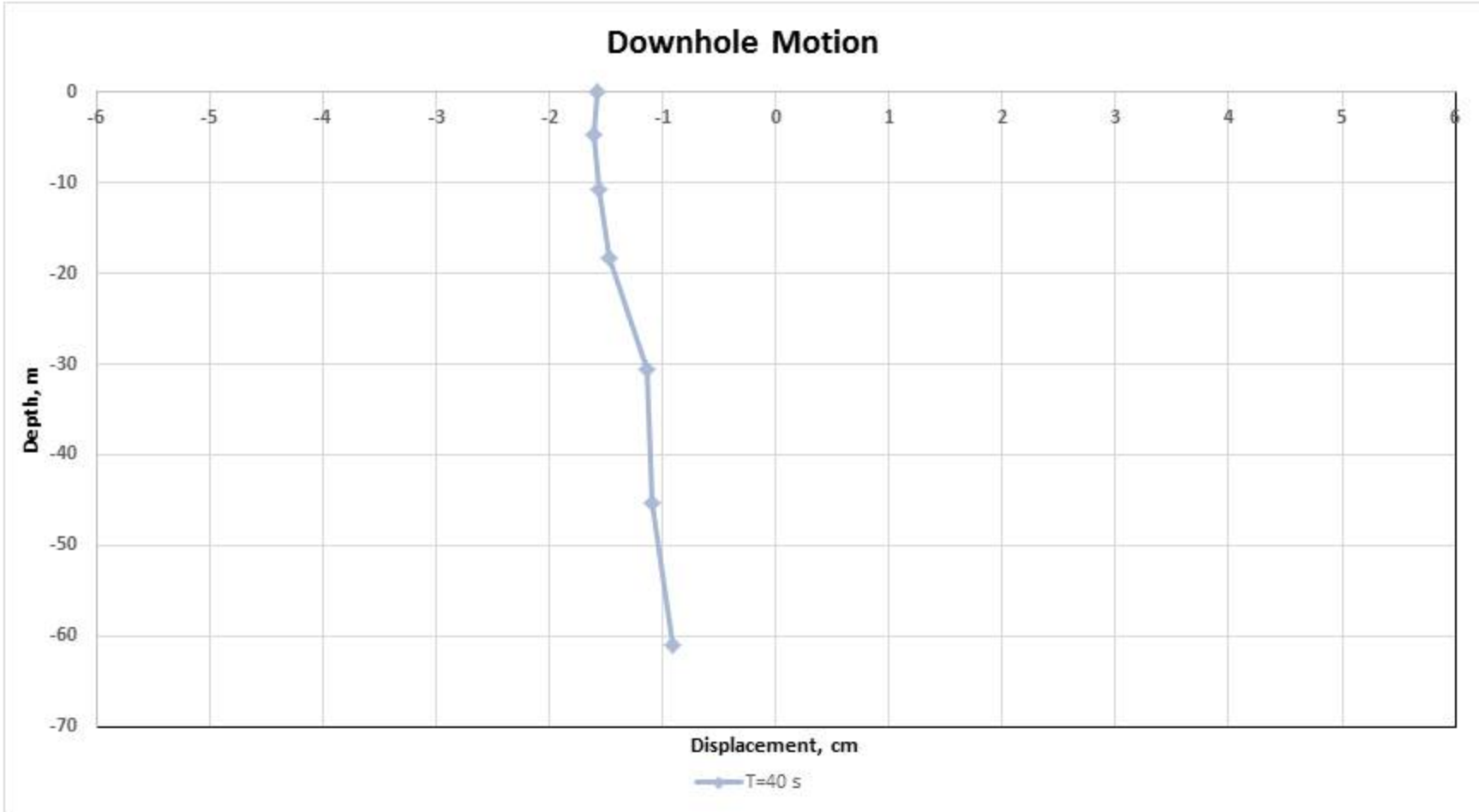

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=30 s

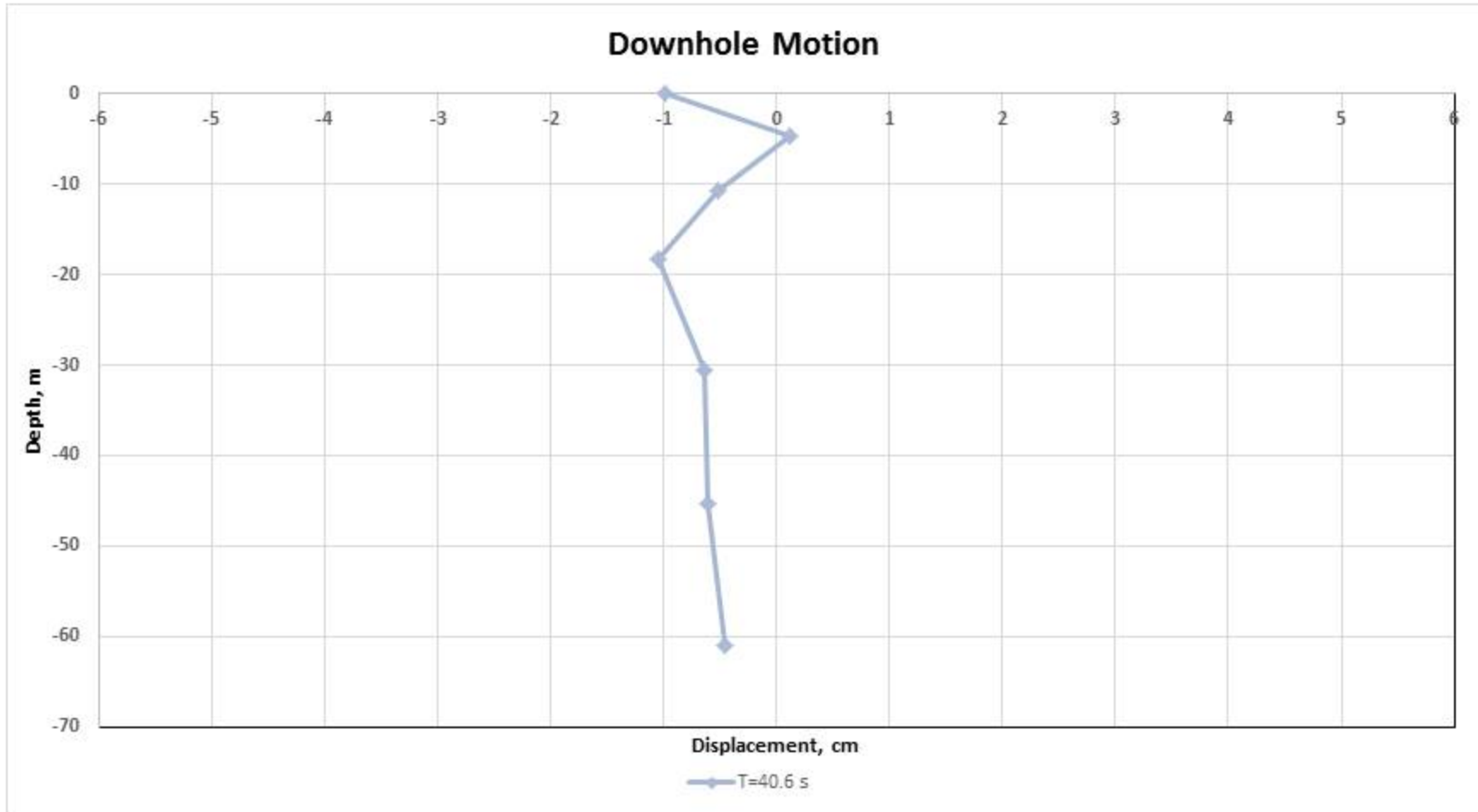

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=32 s

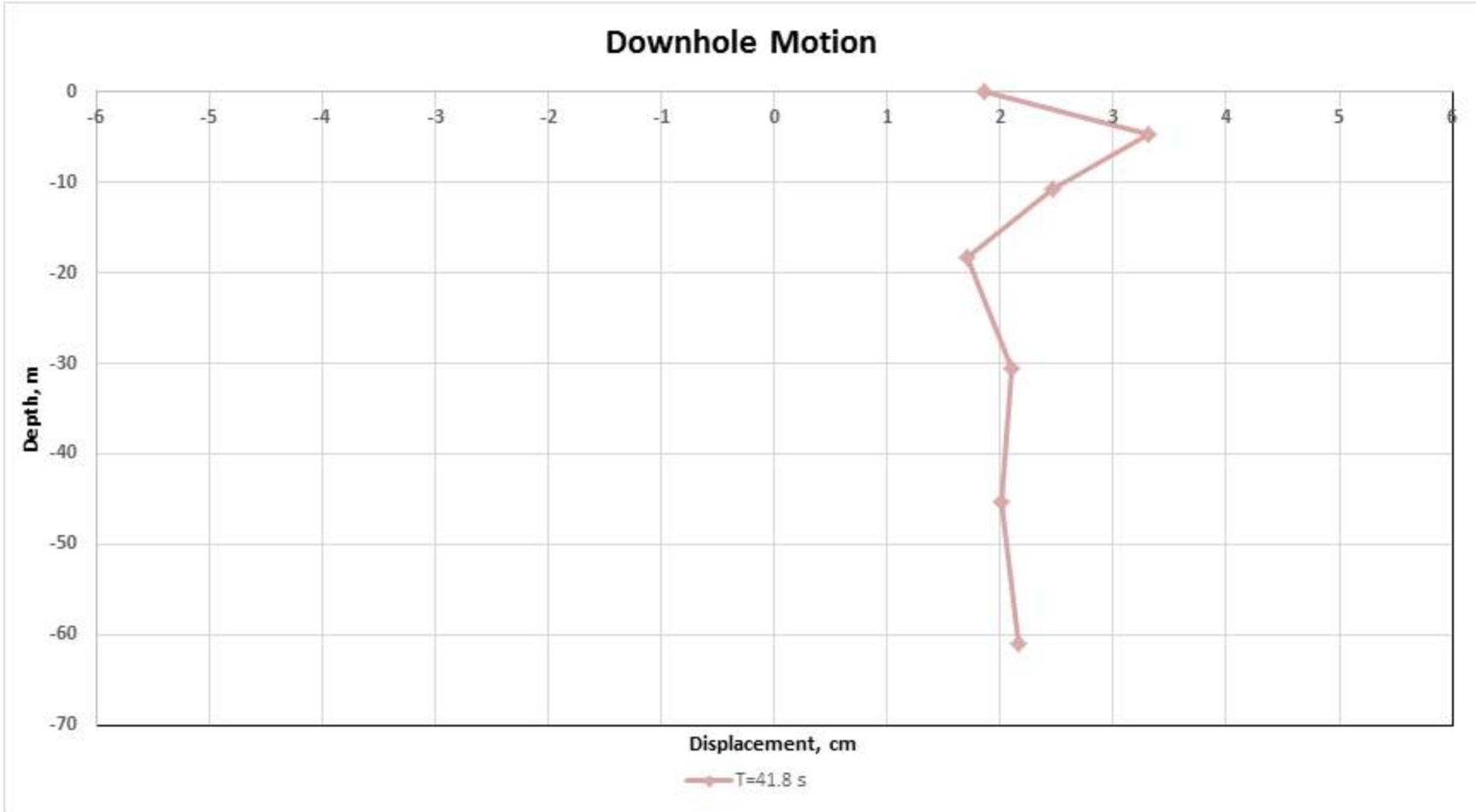

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=35.2 s

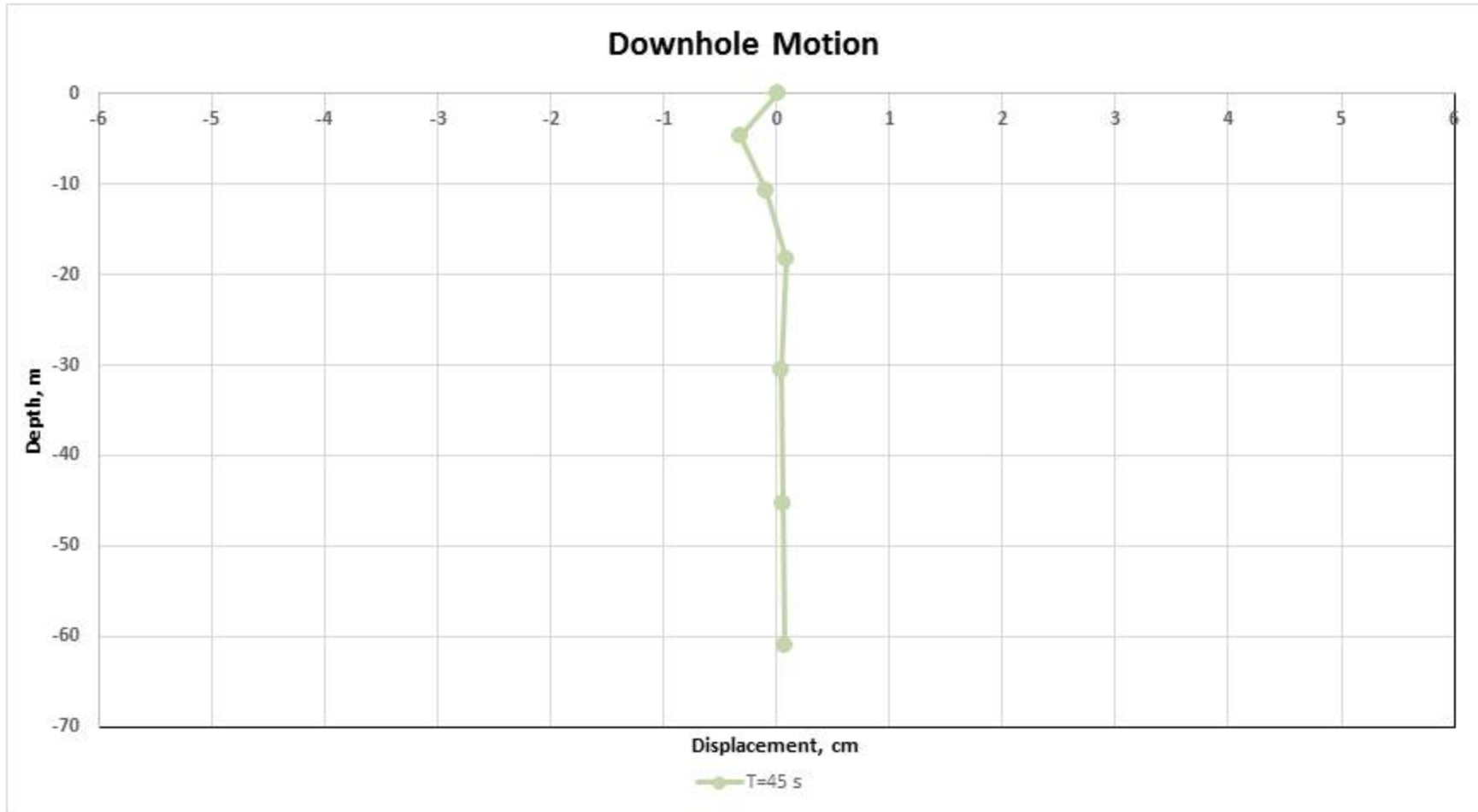

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=36.6 s

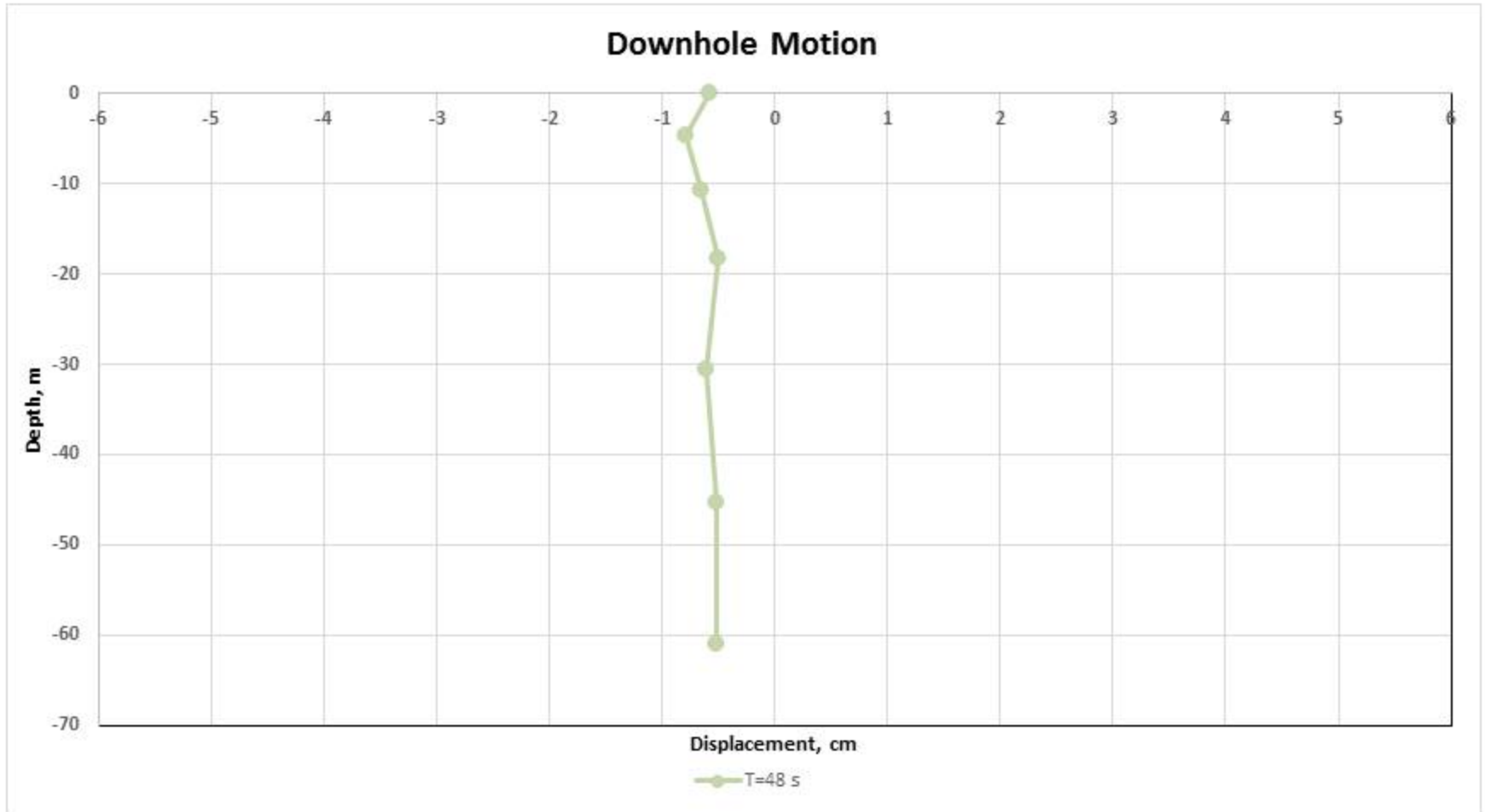

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=37.9

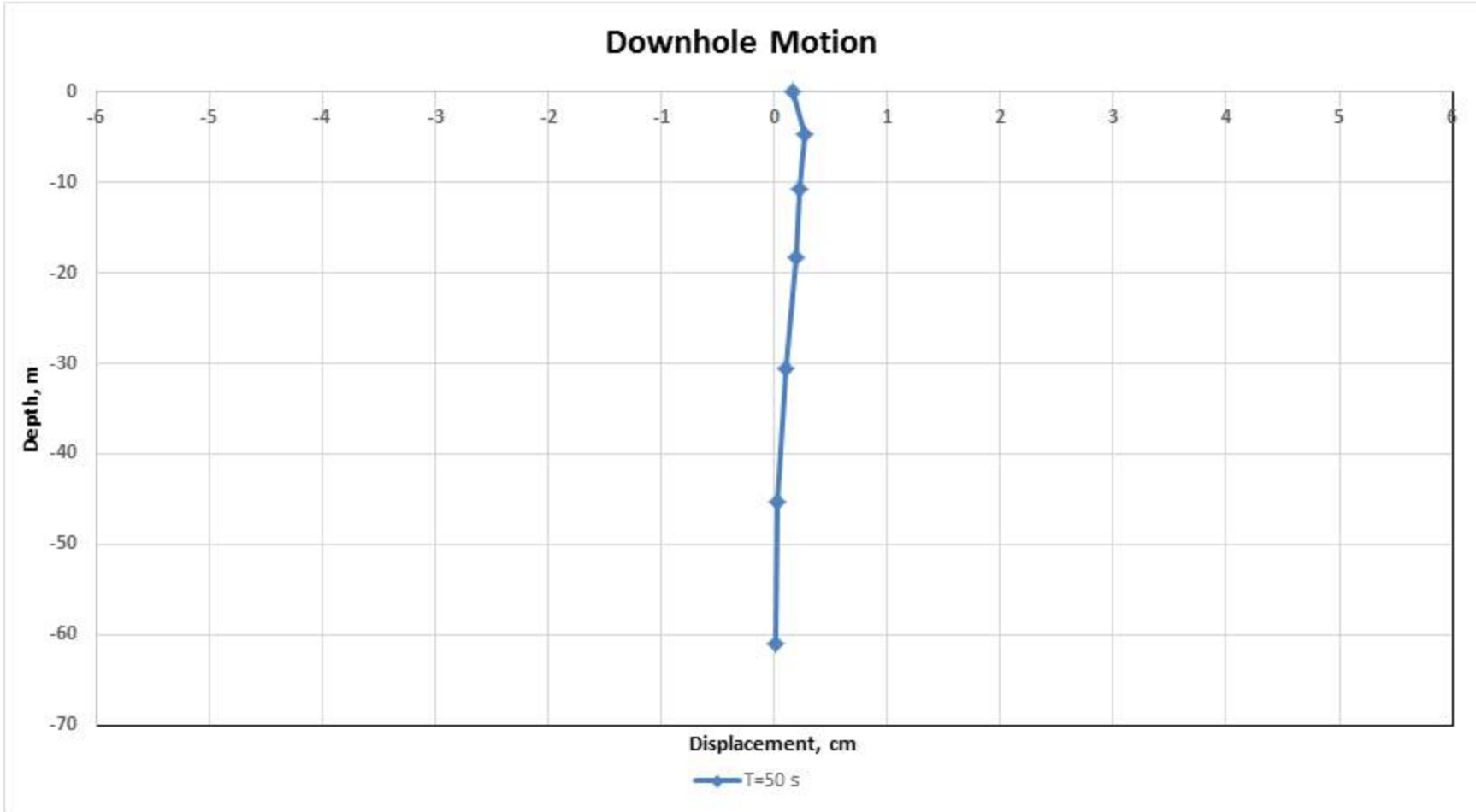

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=40 s


Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=40.6 s

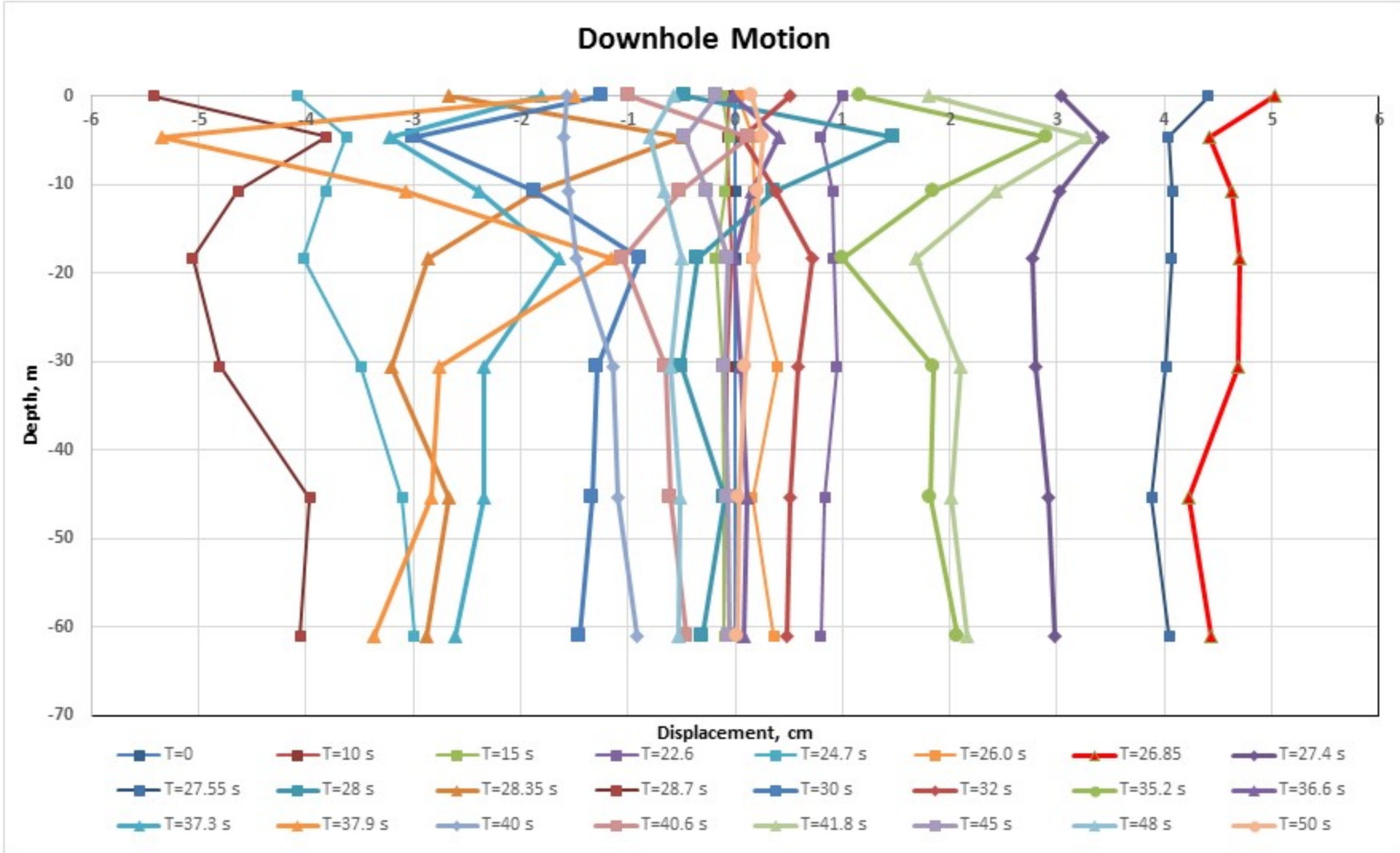

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=41.8 s


Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=45 s

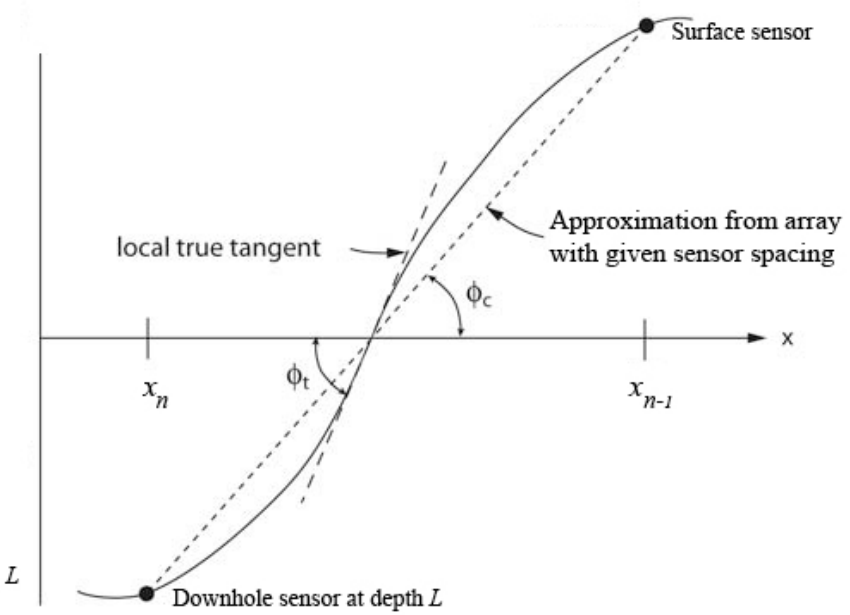

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=48 s


Downhole Motion
0
-10
-20
-30
-40
-50
-60
-70
Depth, m
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Displacement, cm
T=50 s

Displacements in Downhole



Deformation

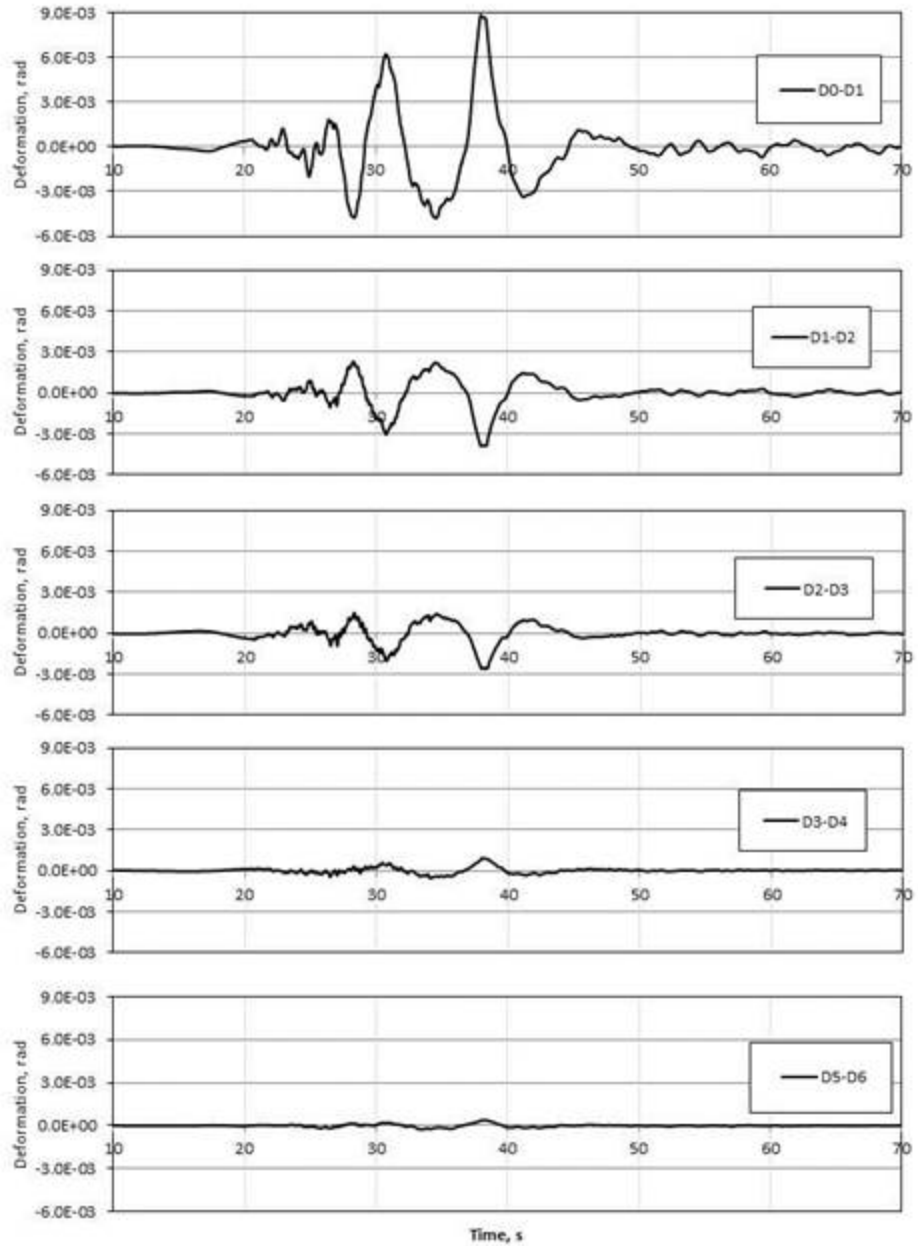


Deformation (simple shear) in the downhole along the *x*-axis

where $x_n(t)$ *and* $x_{n-1}(t)$ are amplitudes of horizontal ground motions at the same time *t* at different elevations in the downhole, and *L* is the distance between those elevations measurements (base).

Simple shear strain with the rate γ is the combination of pure shear strain with the rate γ/2 and rotation with the rate of α=γ/2.

Deformations at Depths



2.3 m

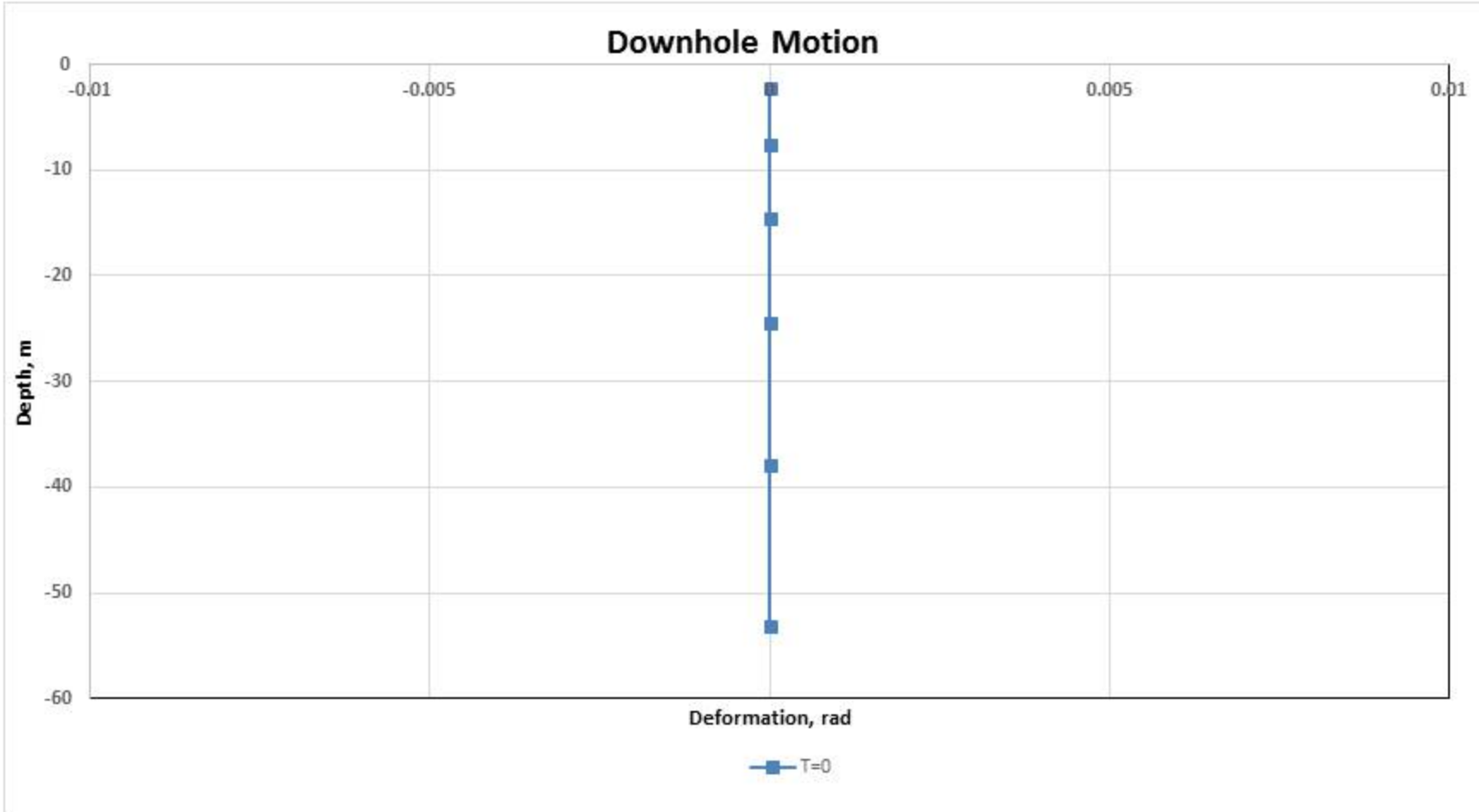
7.6 m

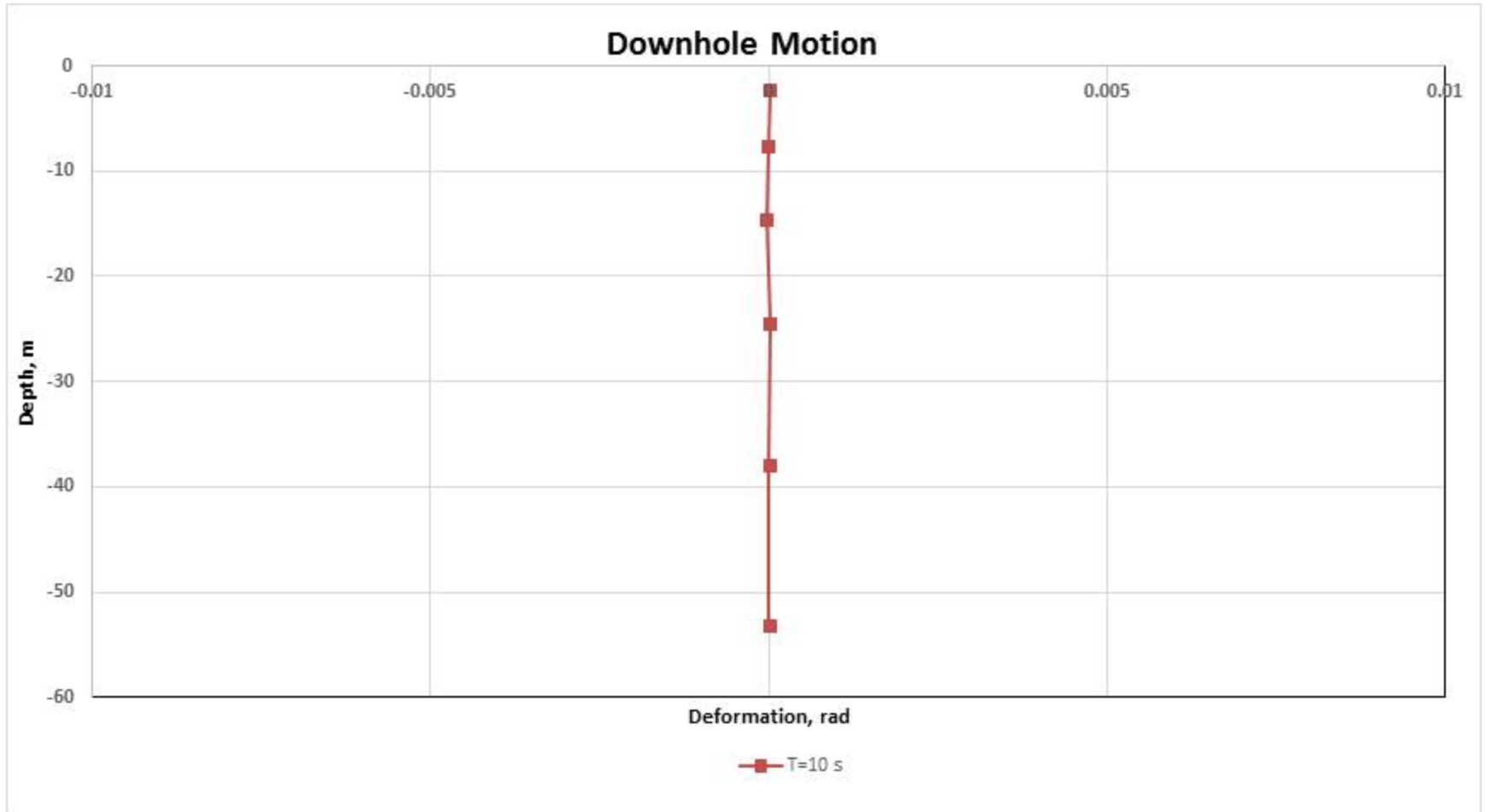
14.5 m

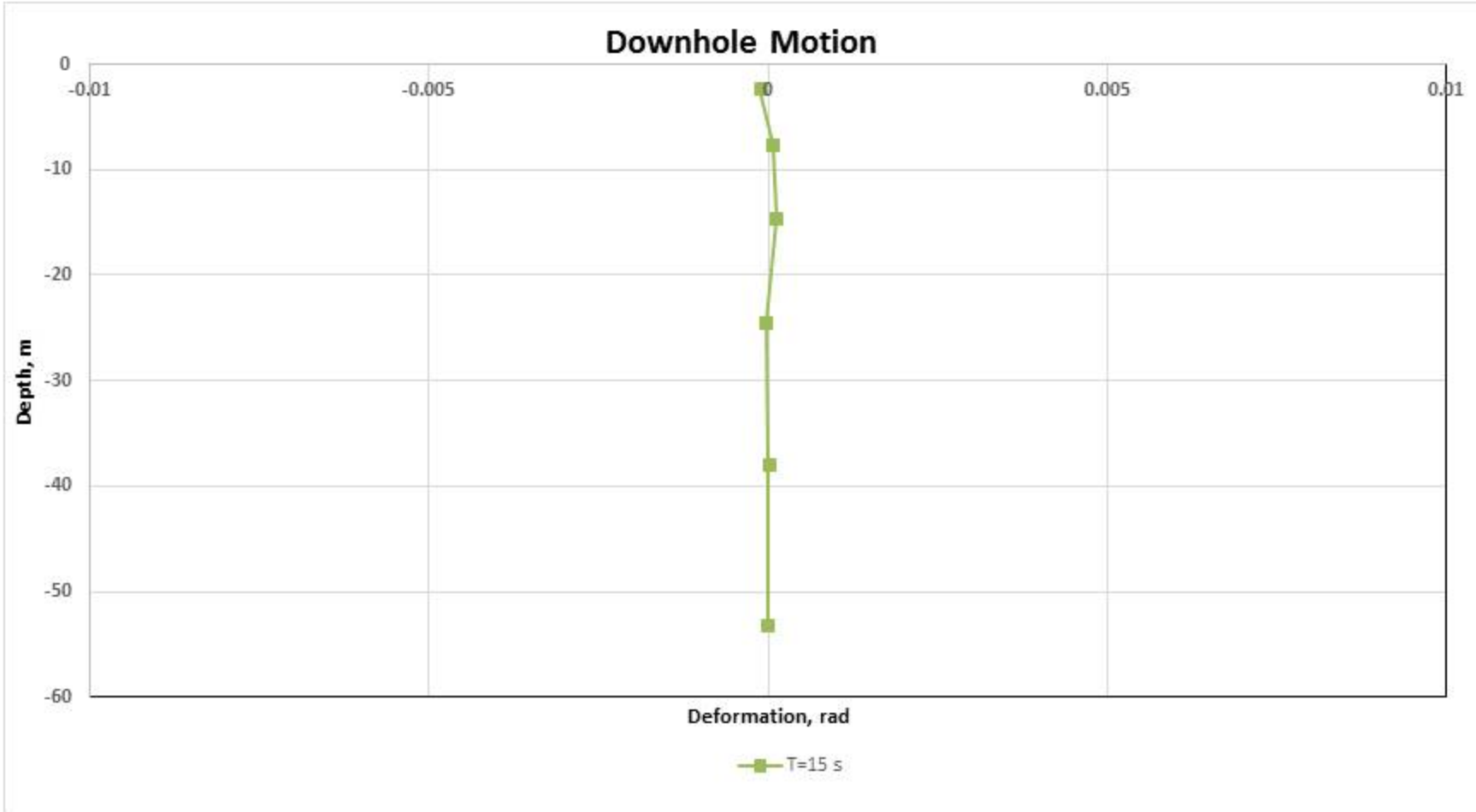
24.4 m

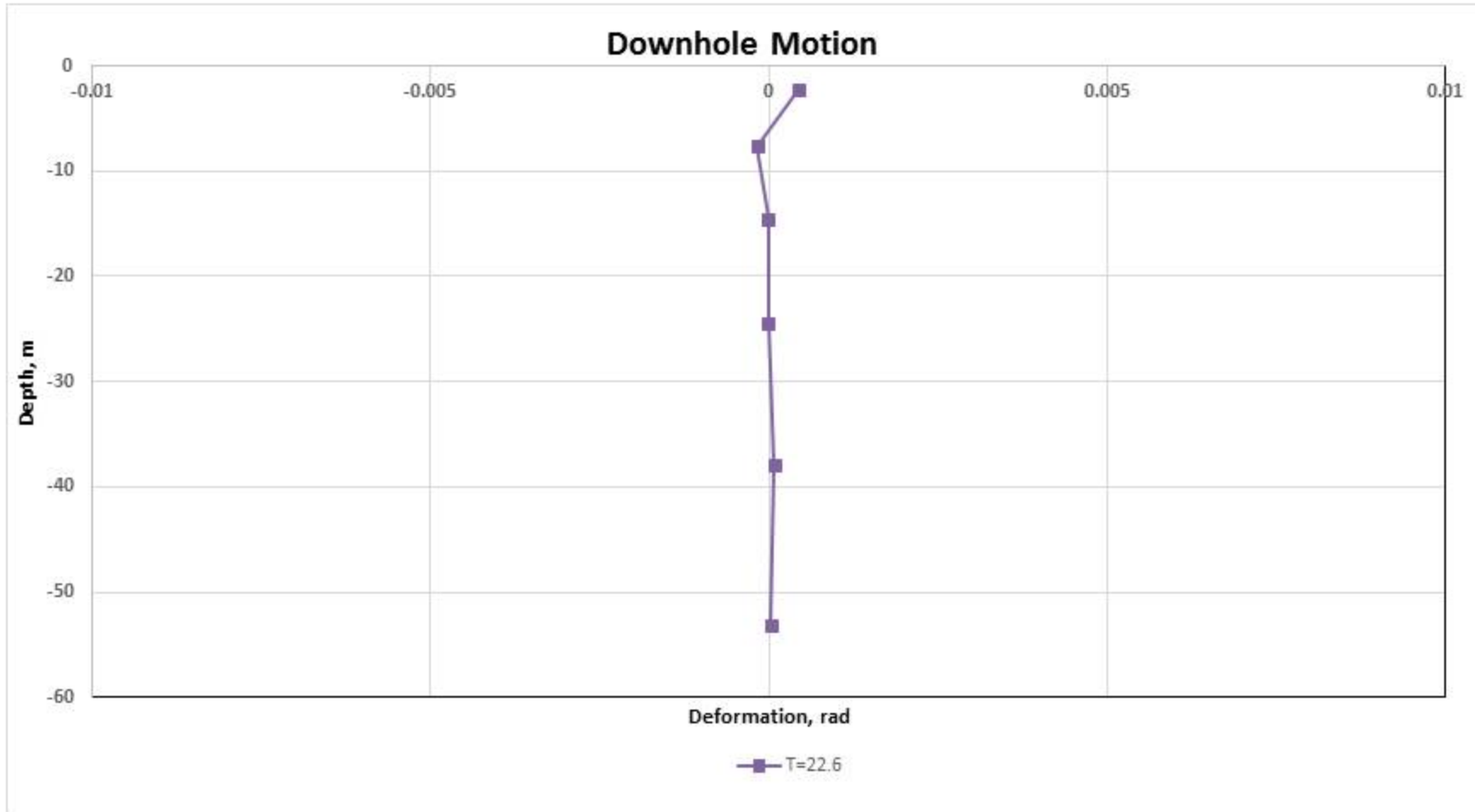
53.2 m

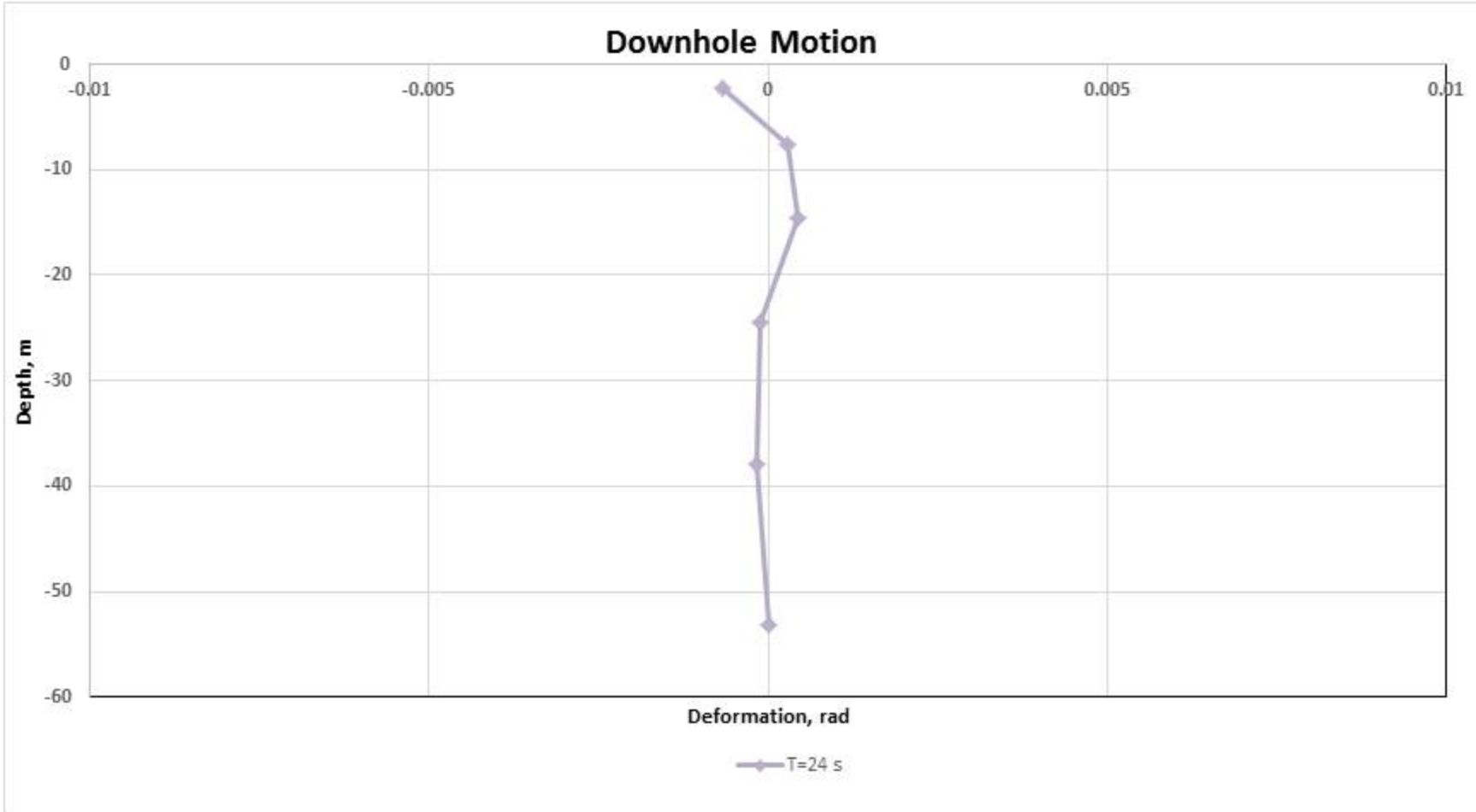
Deformation

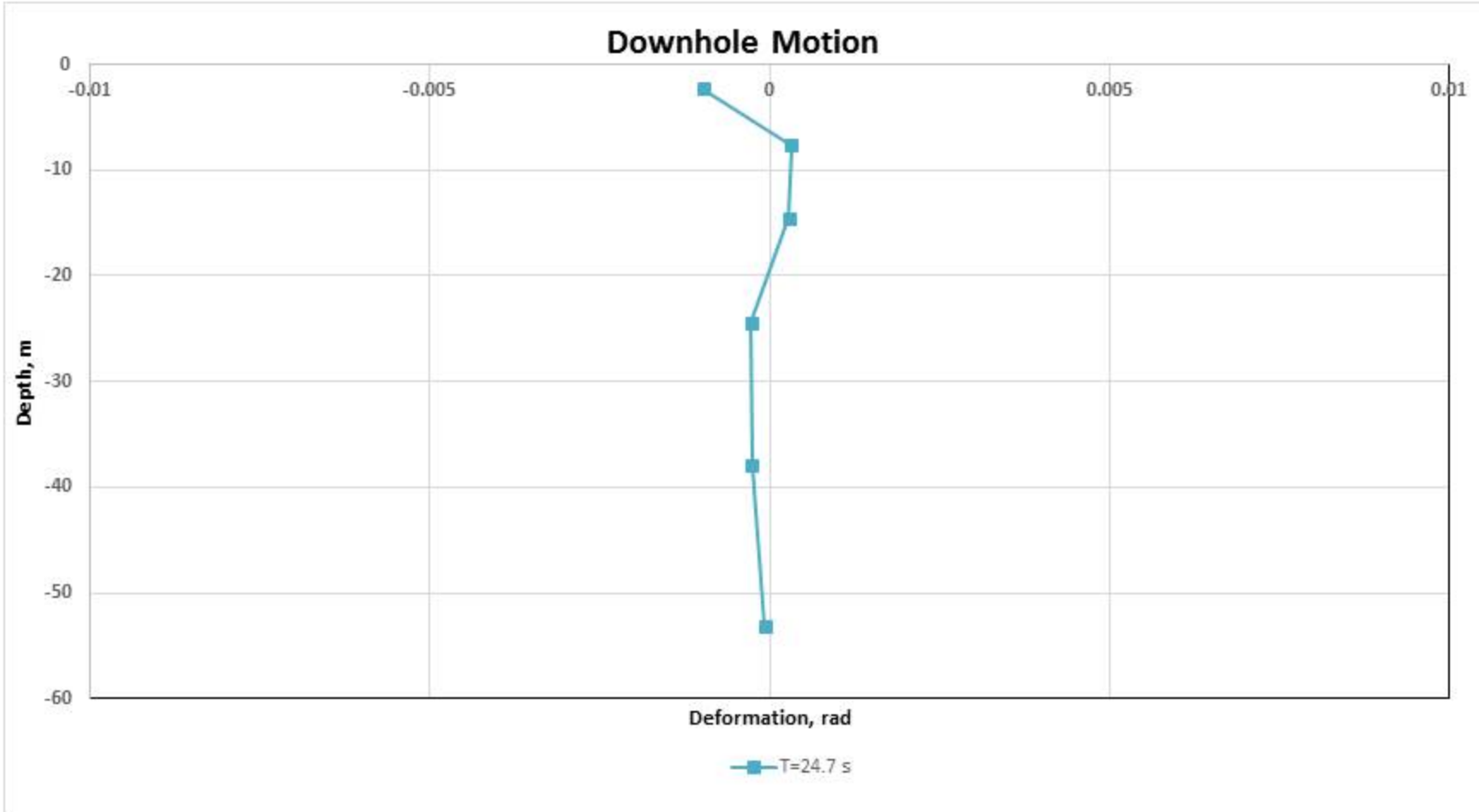

Downhole Motion
0
-10
-20
-30
-40
-50
-60
-0.01
-0.005
0.005
0.01
Depth, m
Deformation, rad
T=0

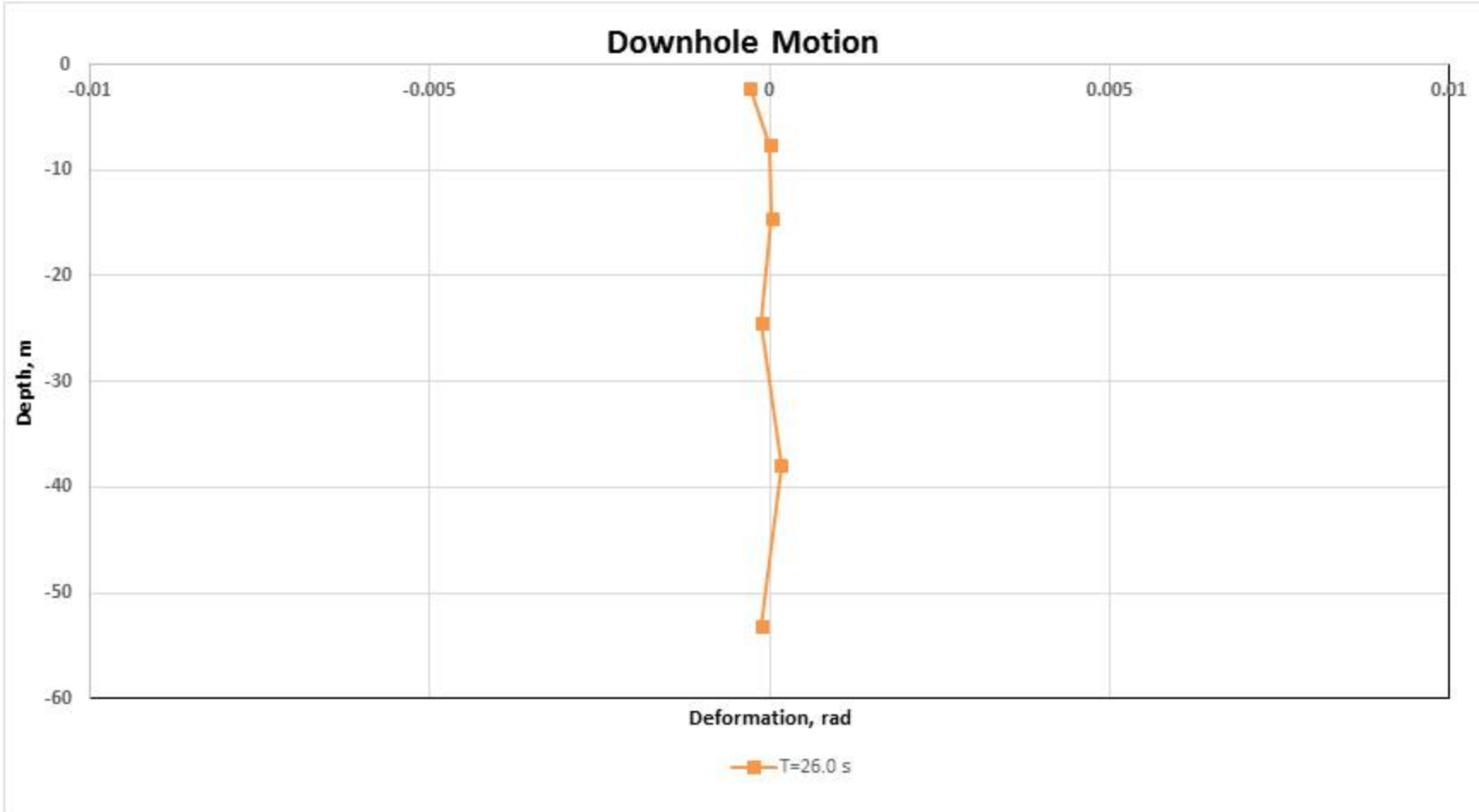

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0.005
0.01
Deformation, rad
T=10 s

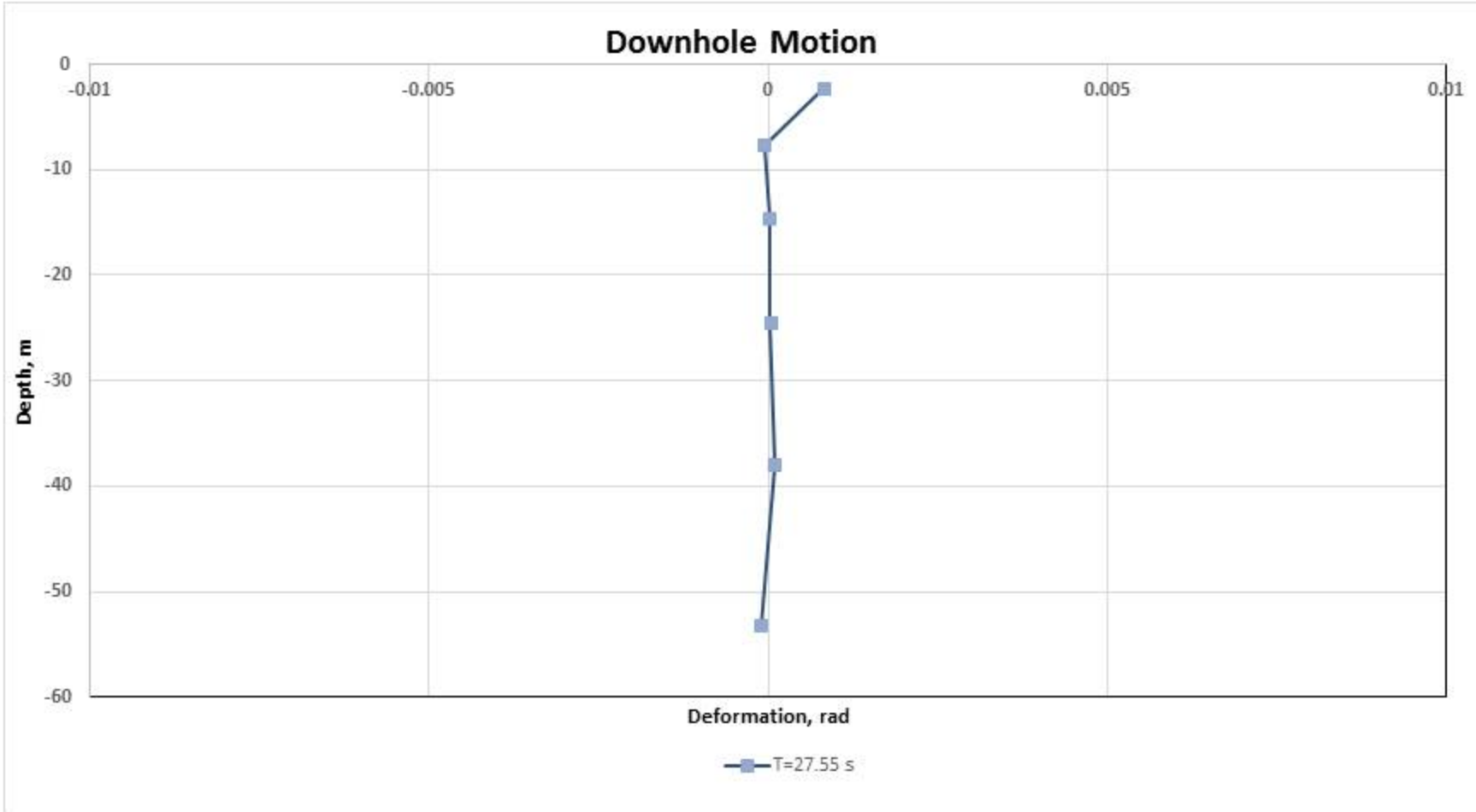

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=15 s

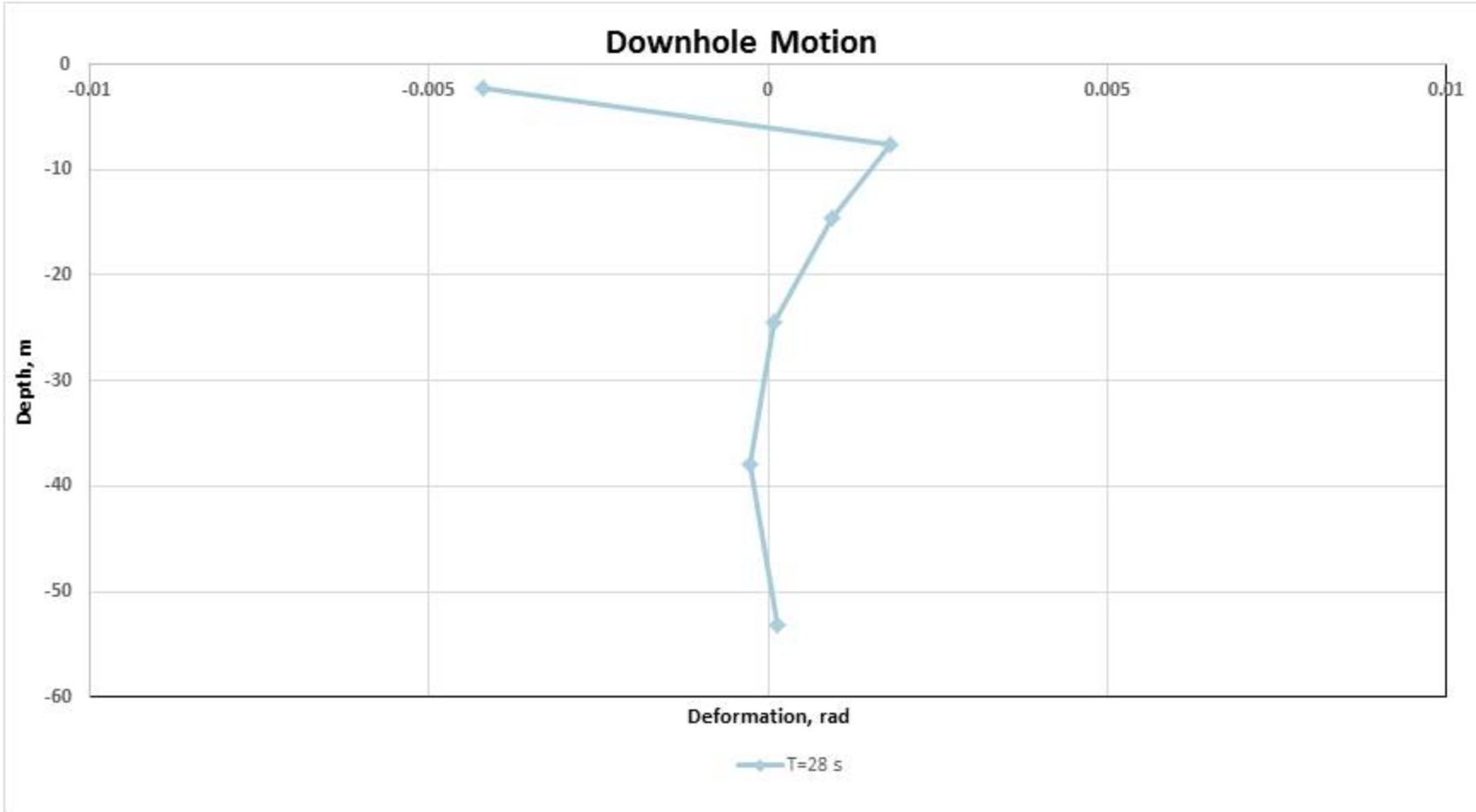

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=22.6

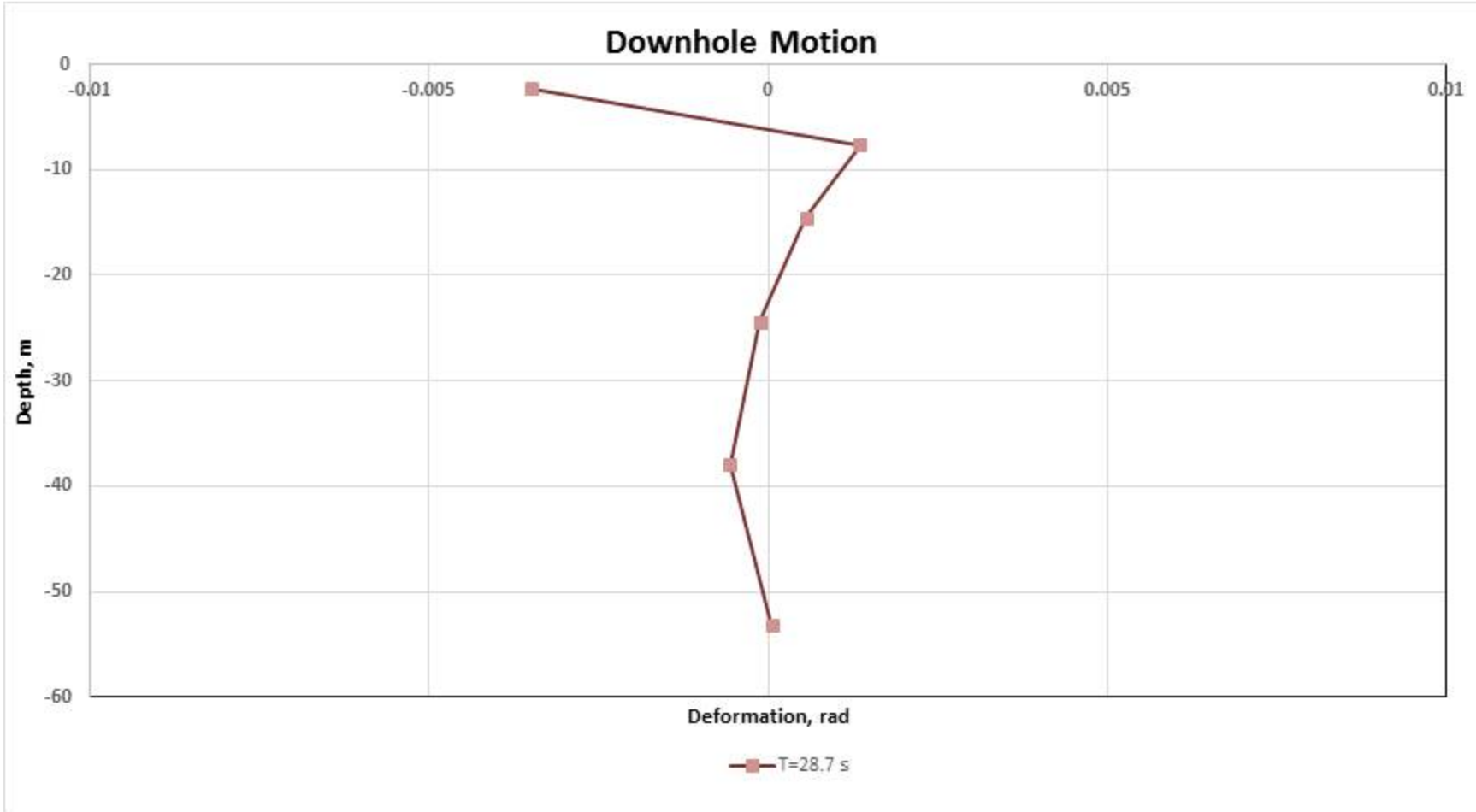

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=24 s

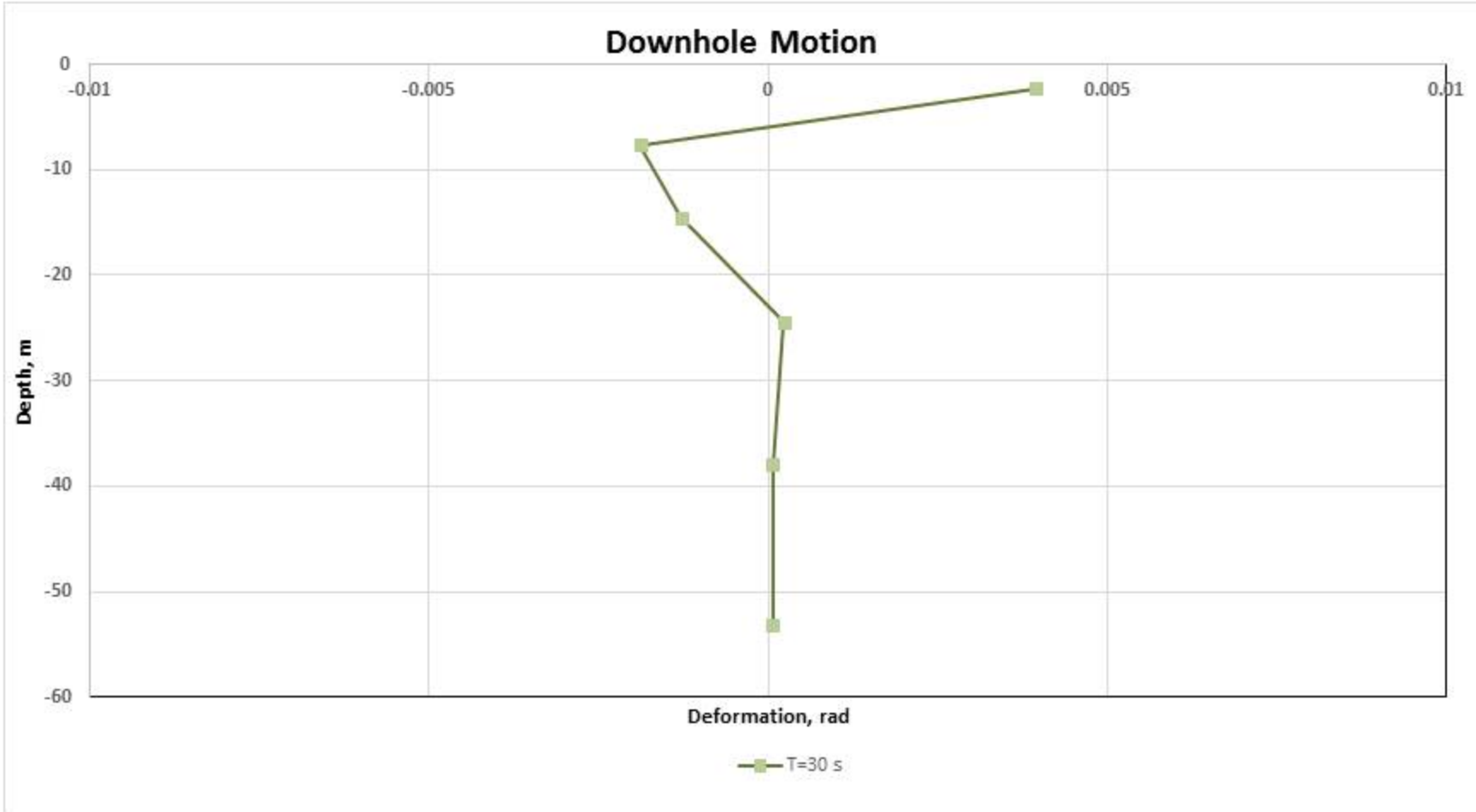

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=24.7 s

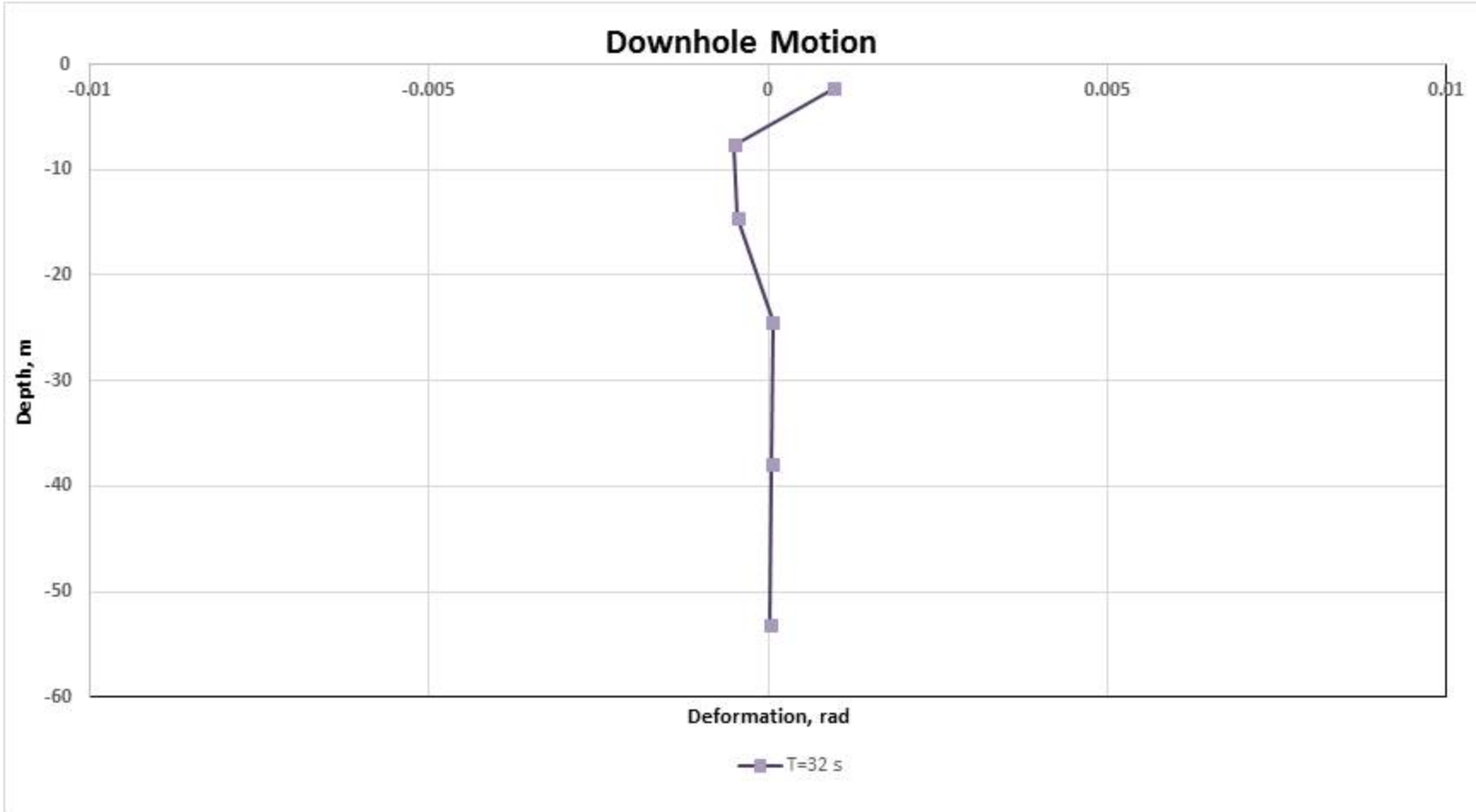

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=26.0 s

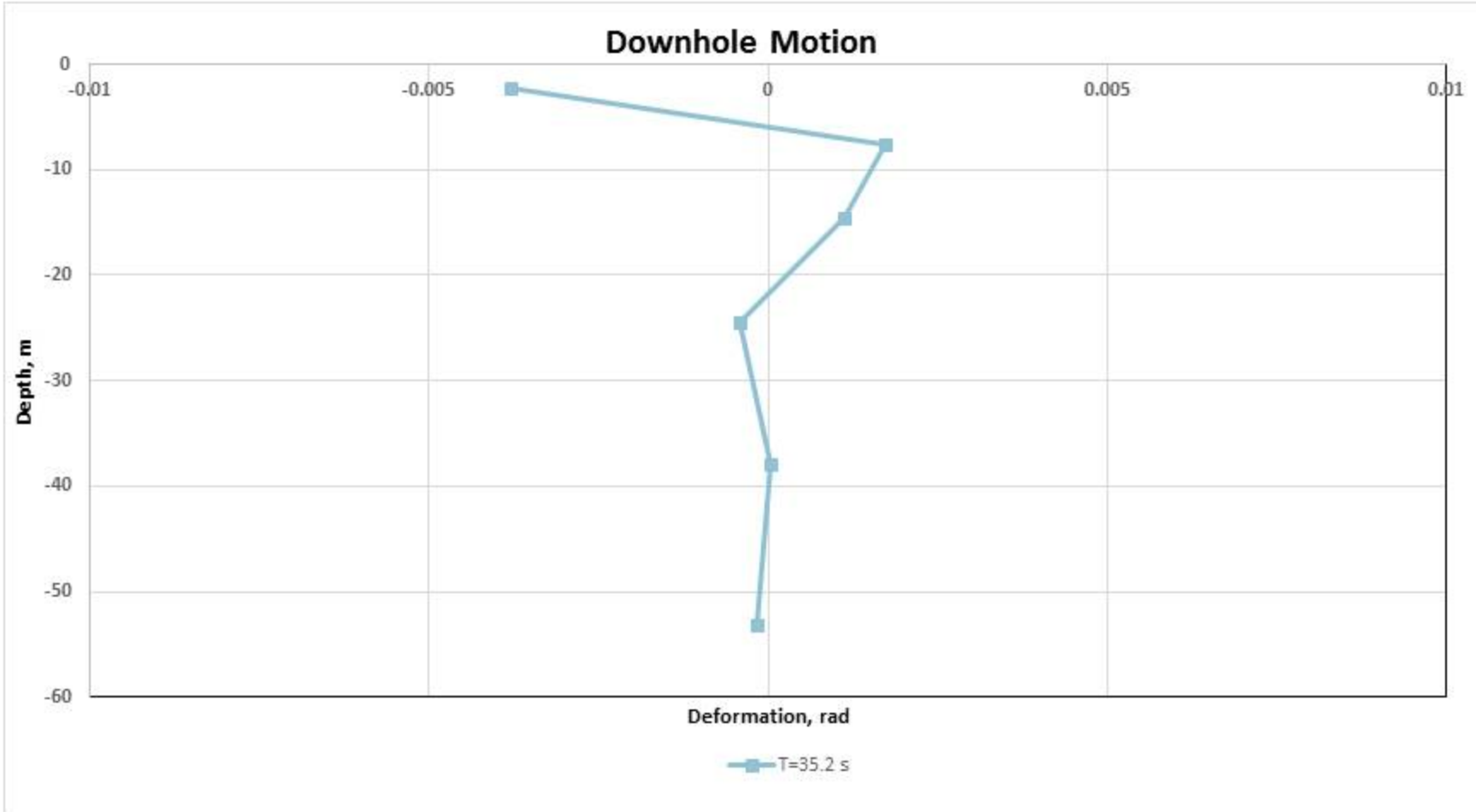

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=27.55 s

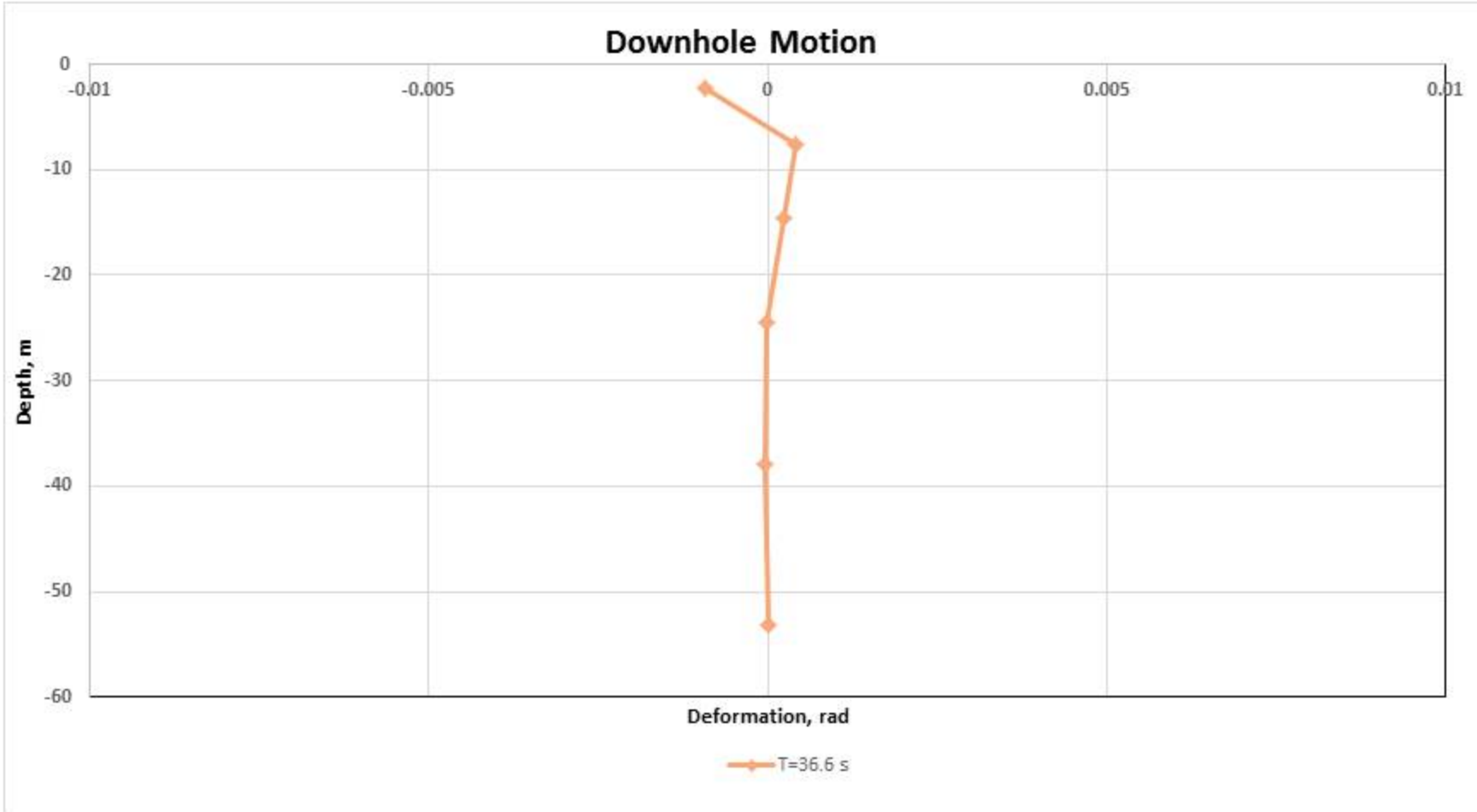

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=28 s

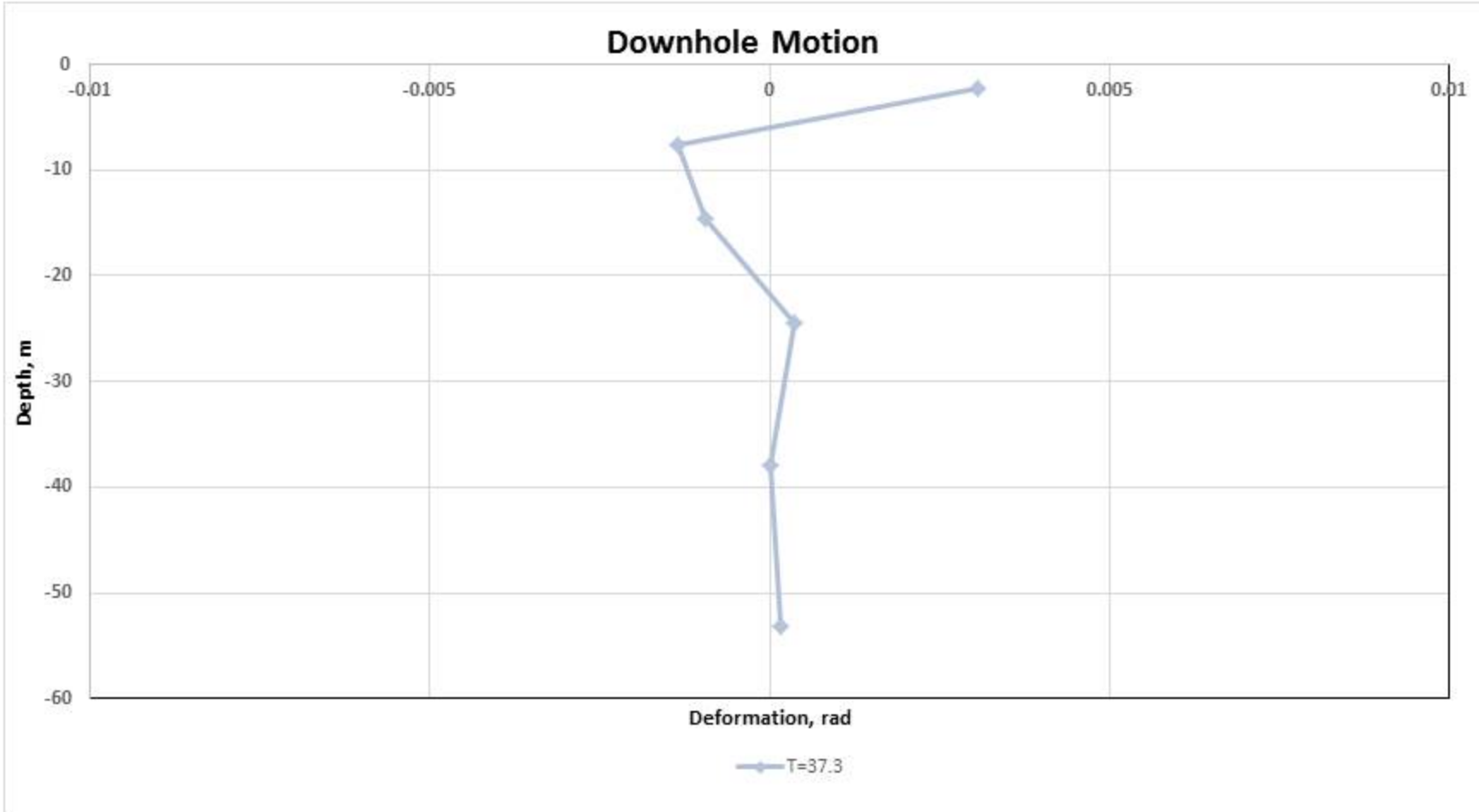

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=28.7 s

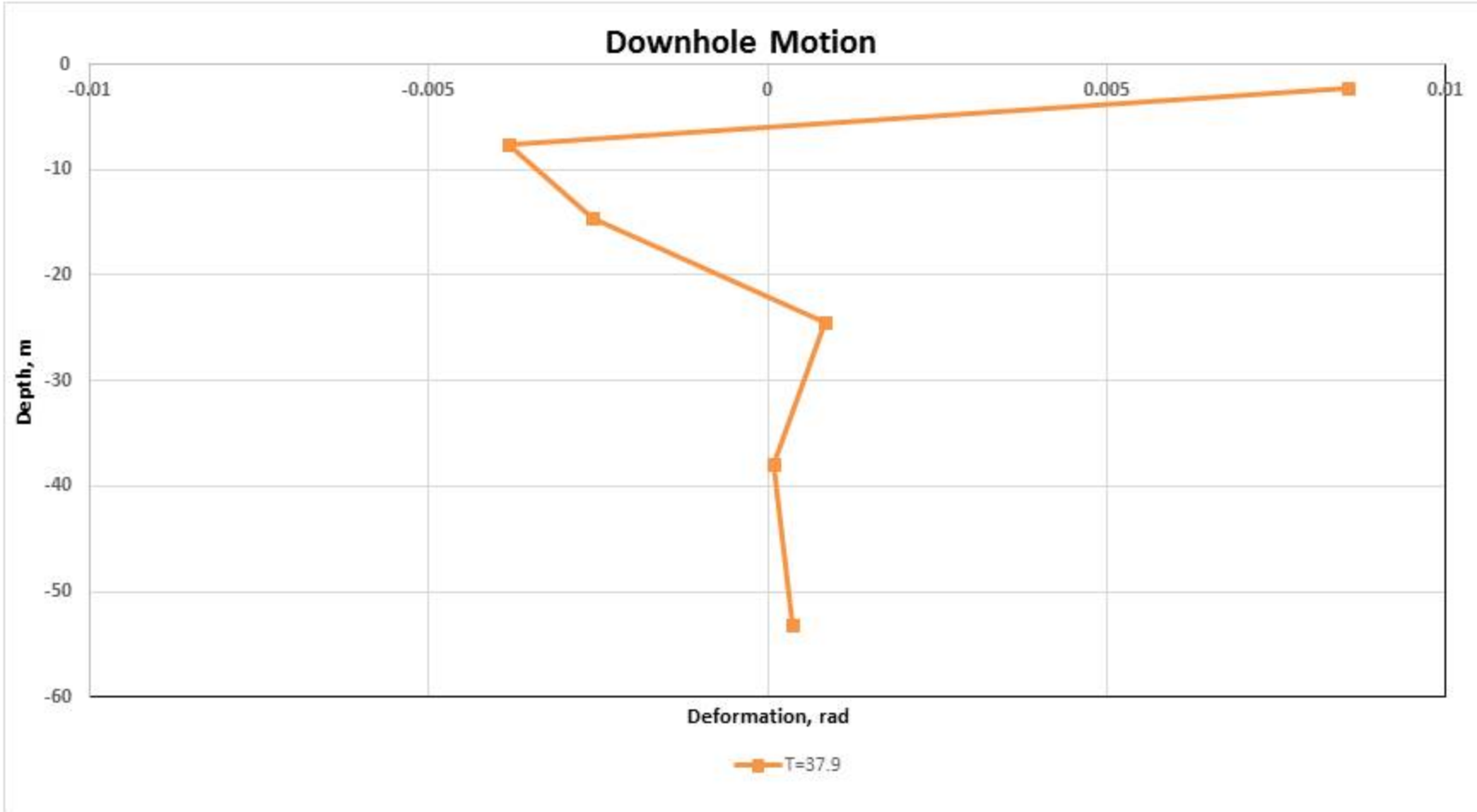

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=30 s

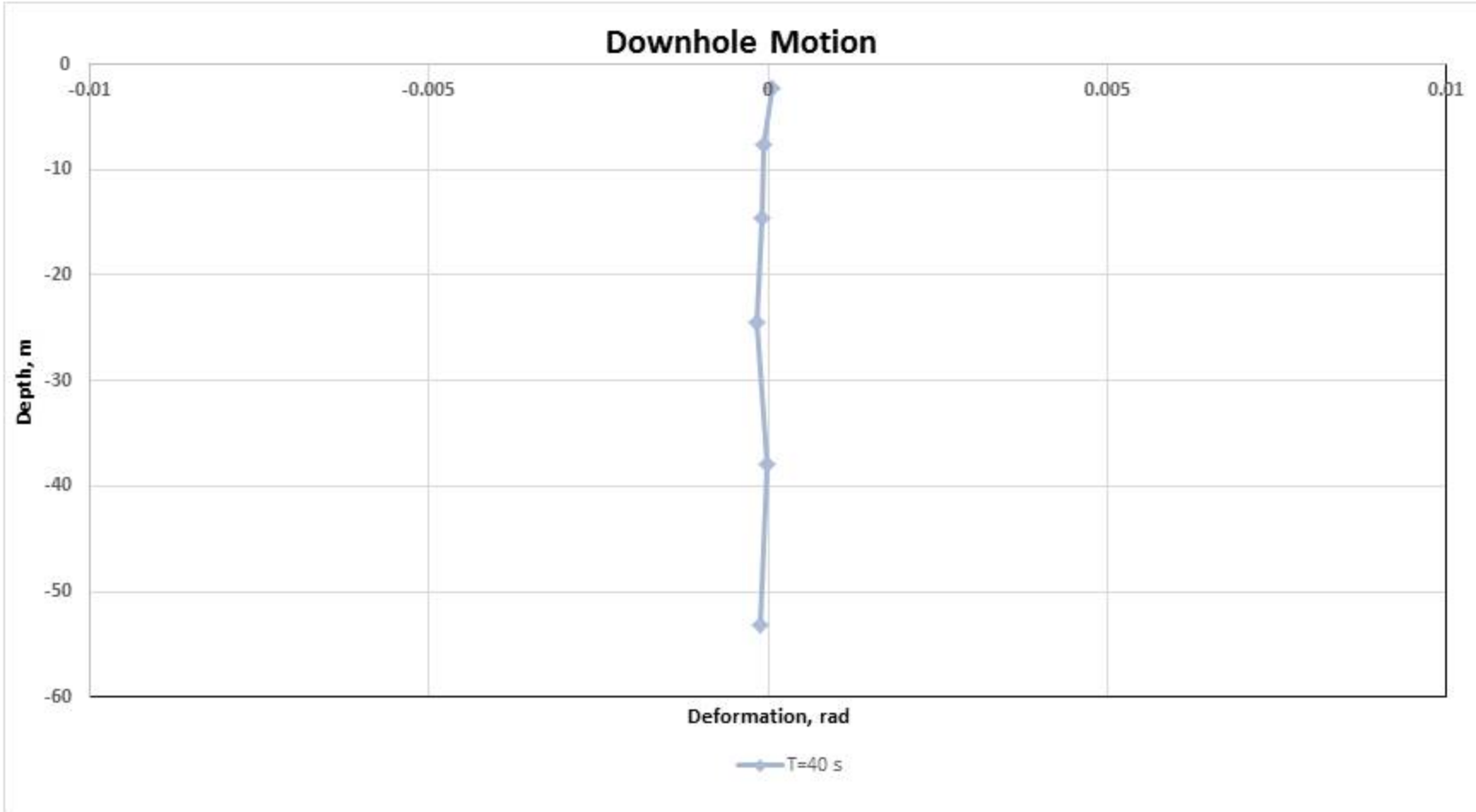

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=32 s

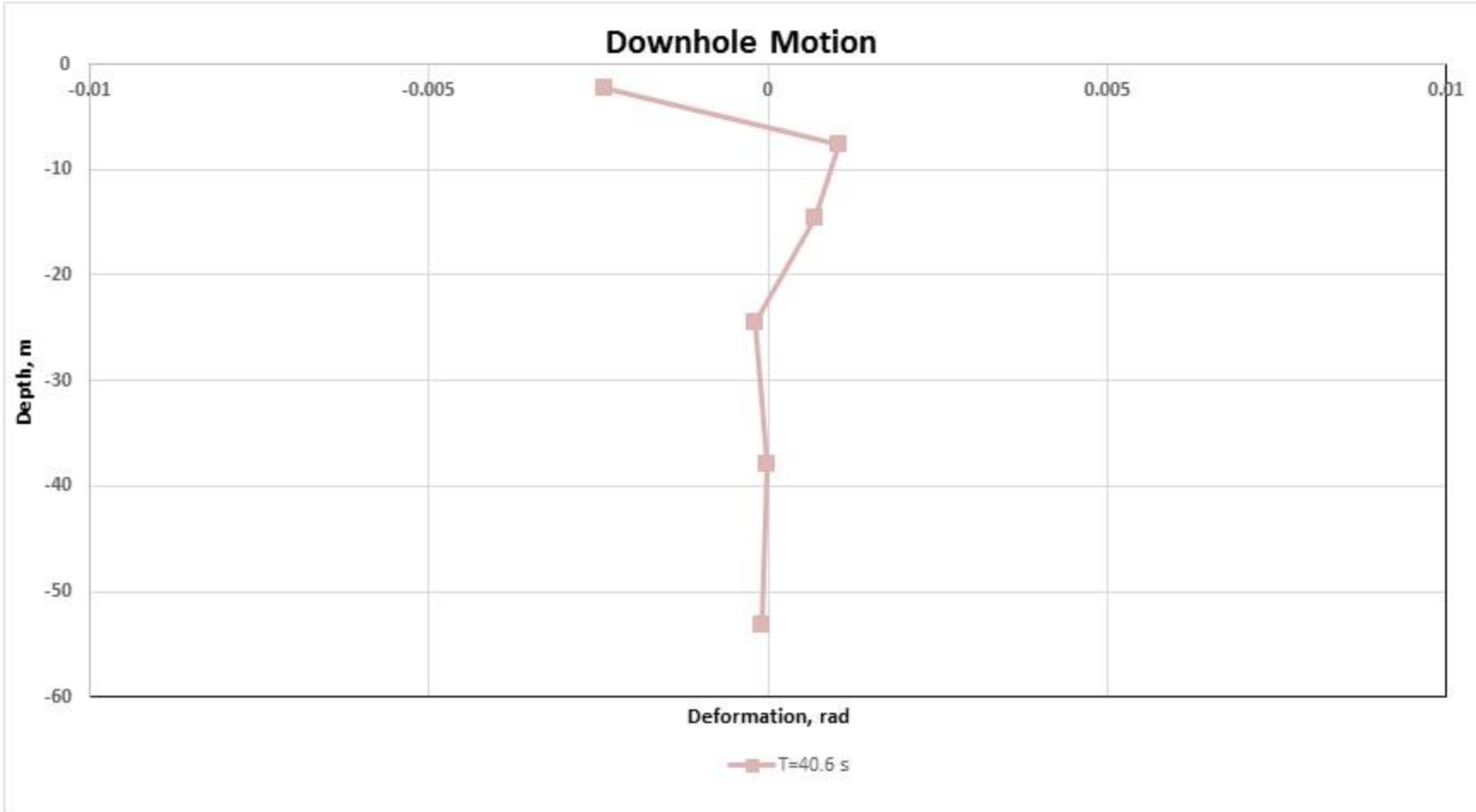

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=35.2 s

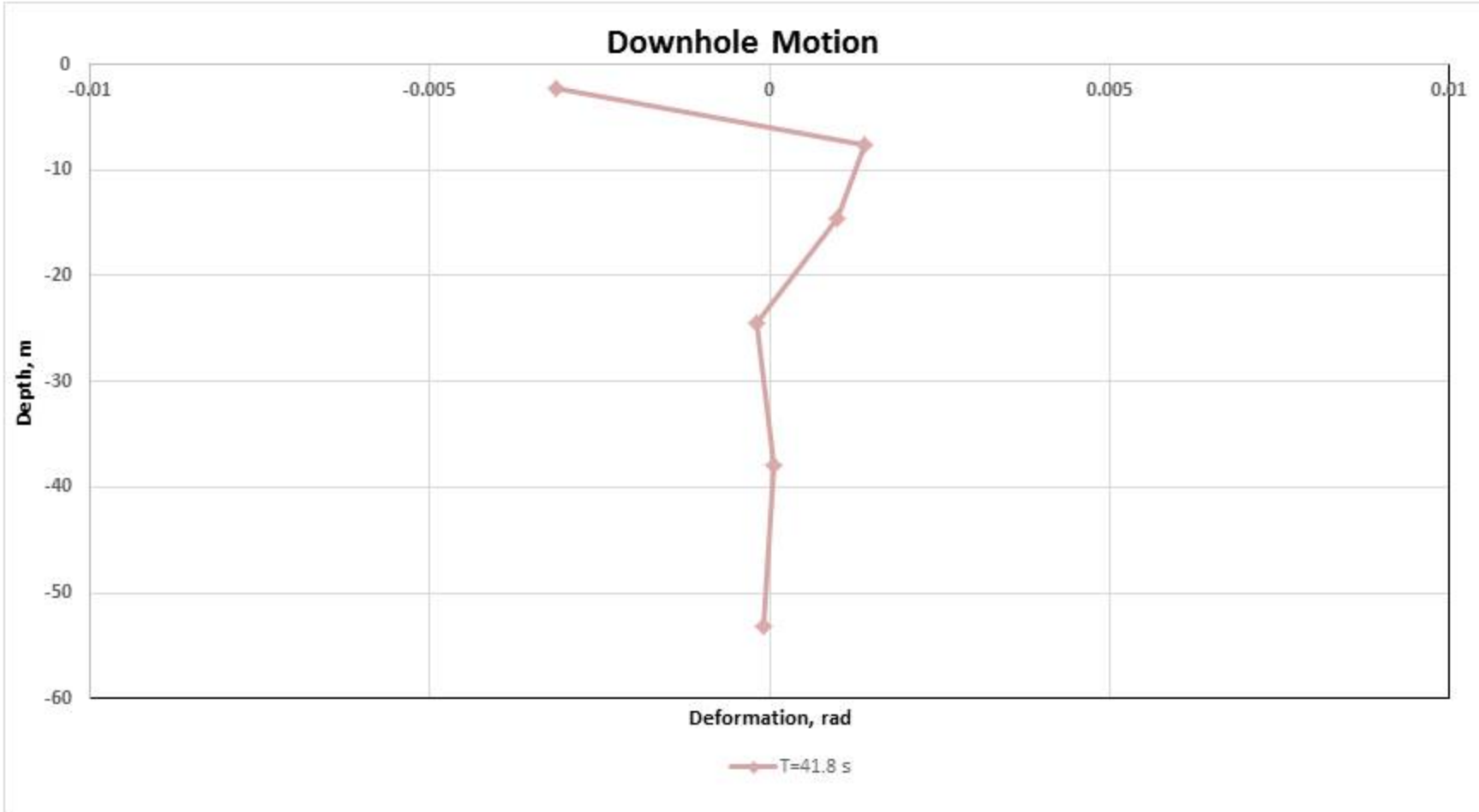

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=36.6 s

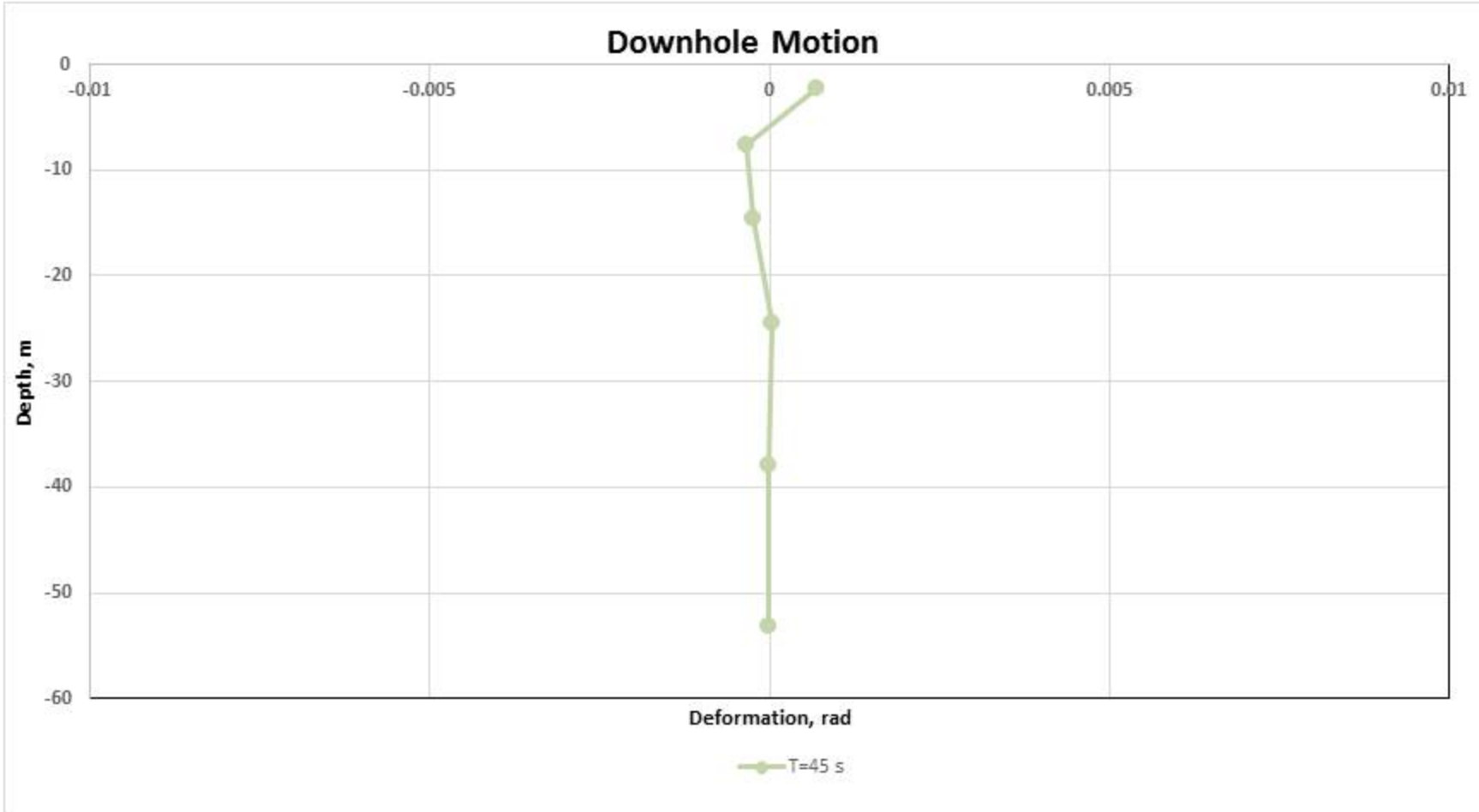

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=37.3

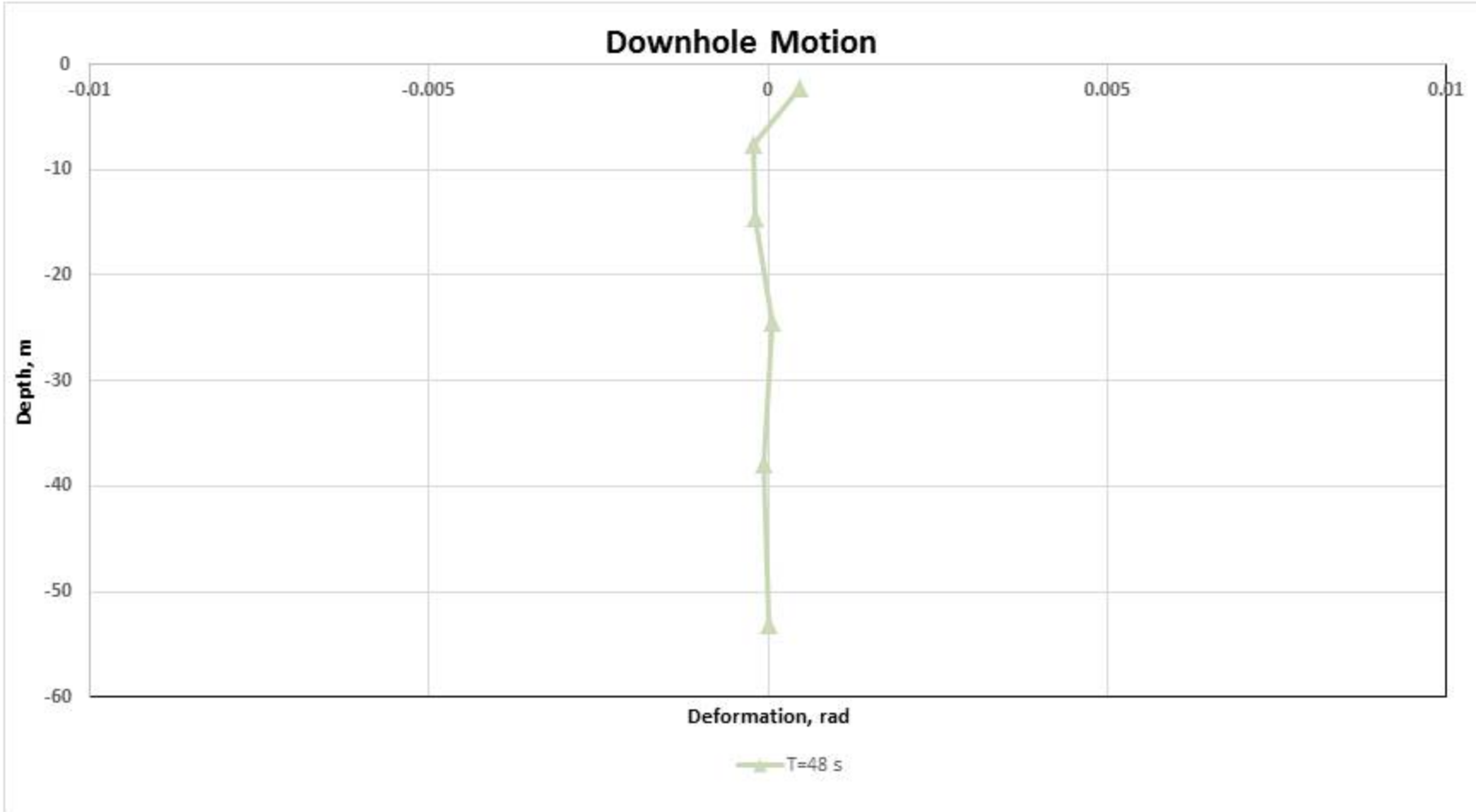

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=37.9

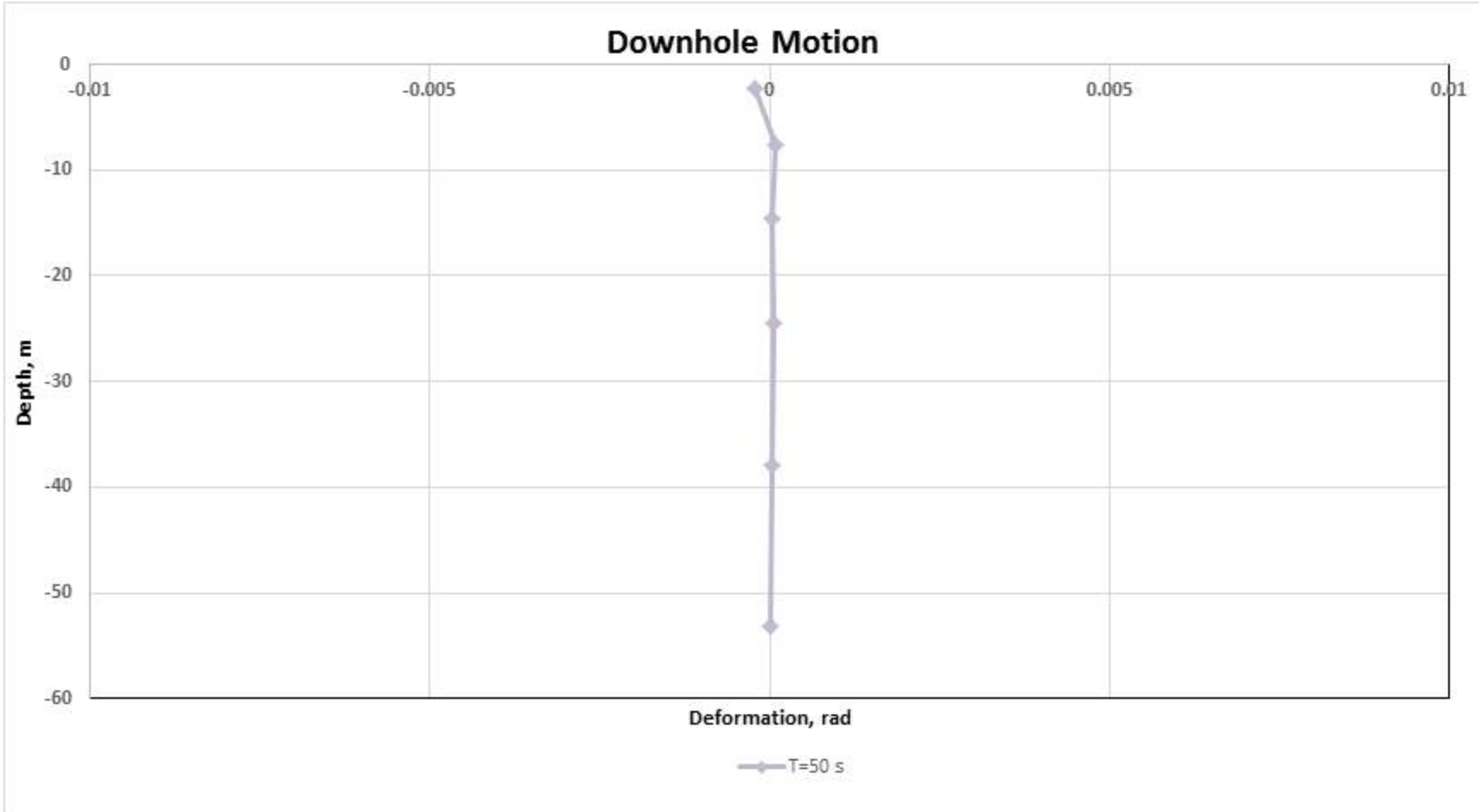

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=40 s

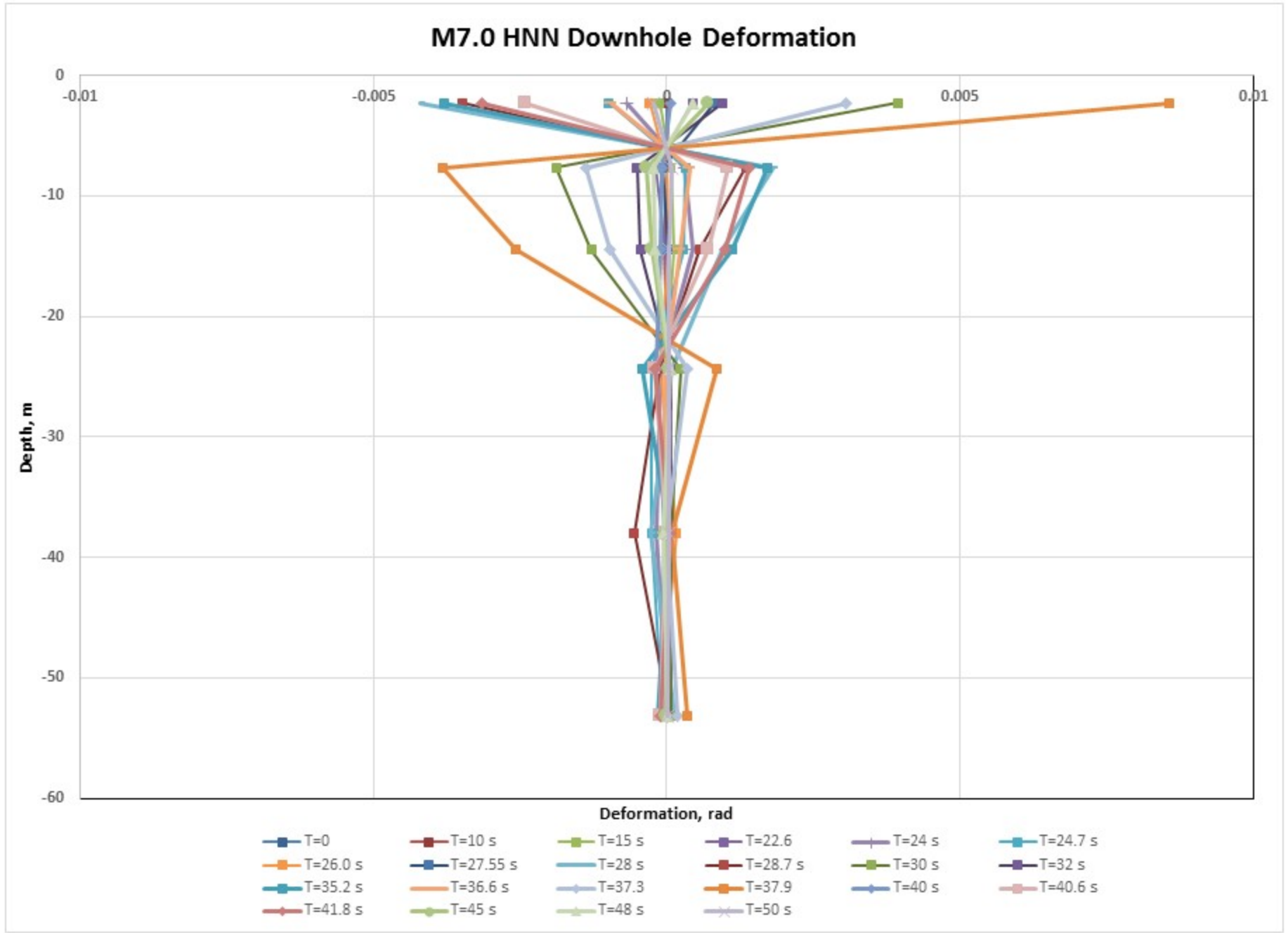

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=40.6 s


Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=41.8 s

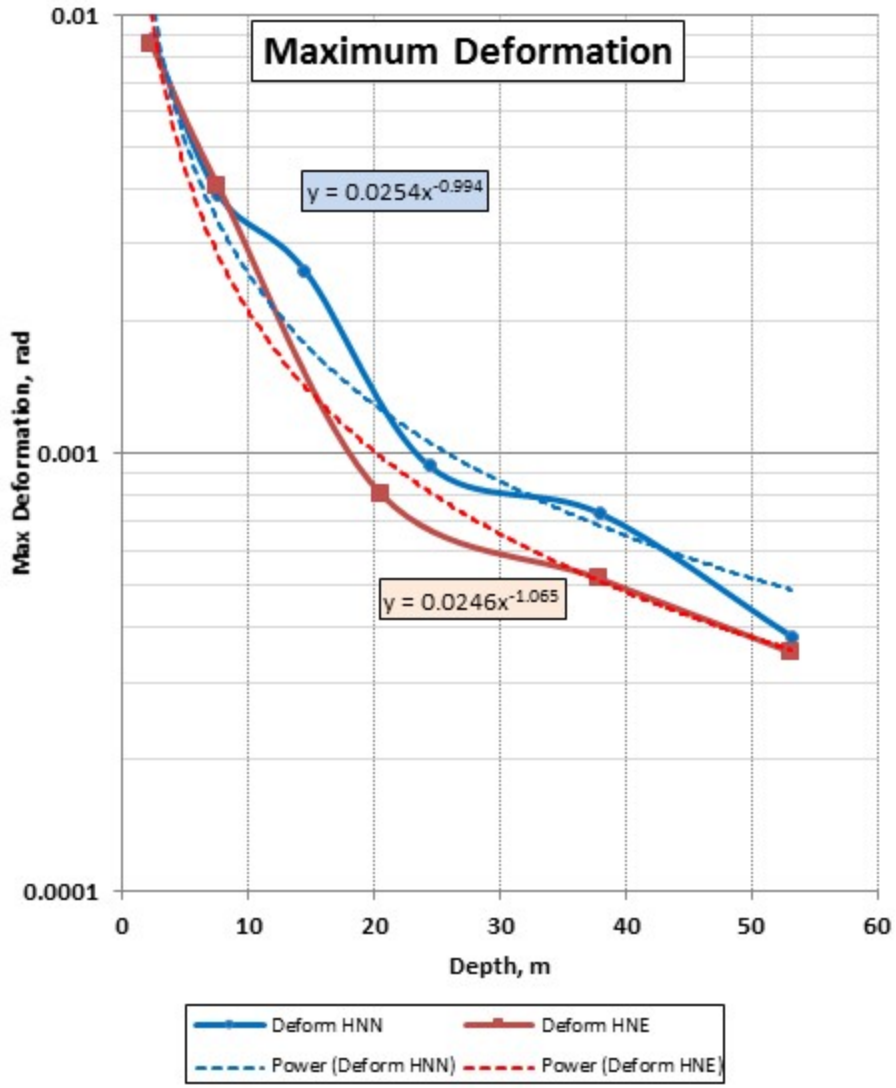

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=45 s

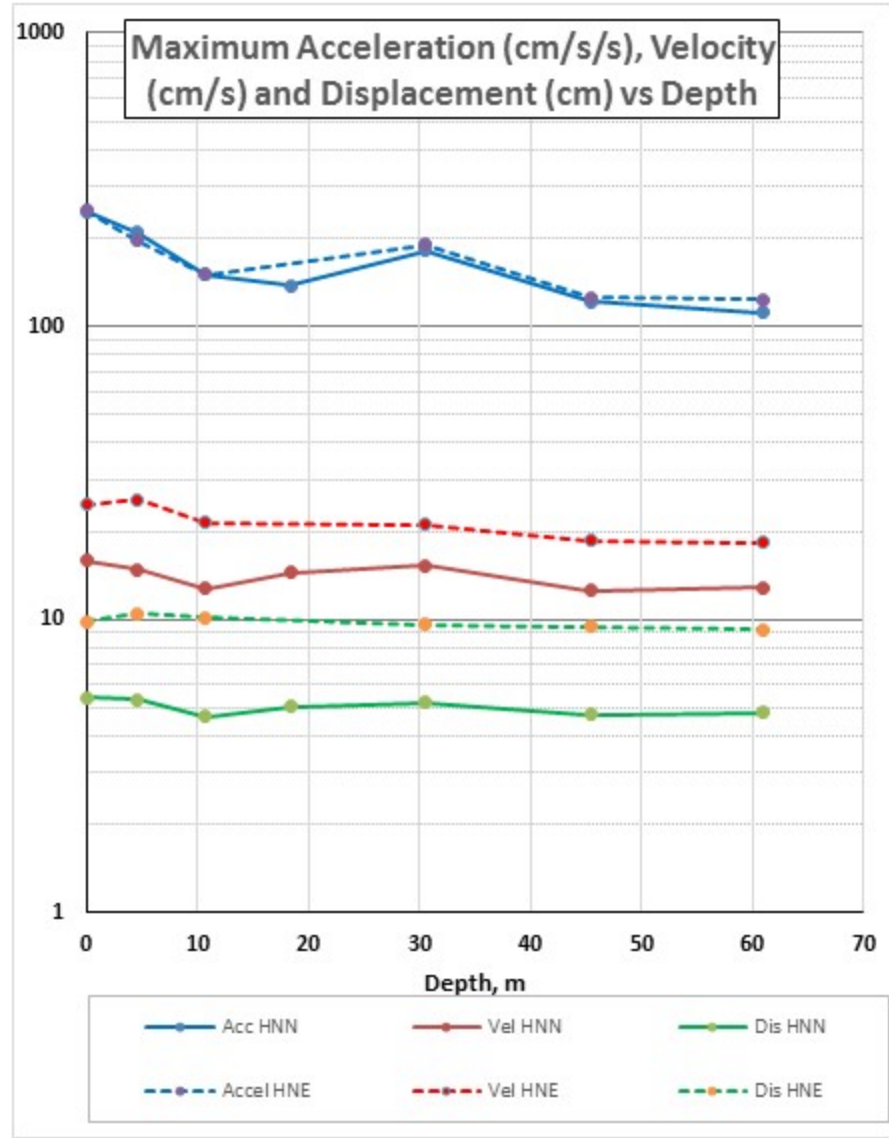

Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=48 s


Downhole Motion
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=50 s

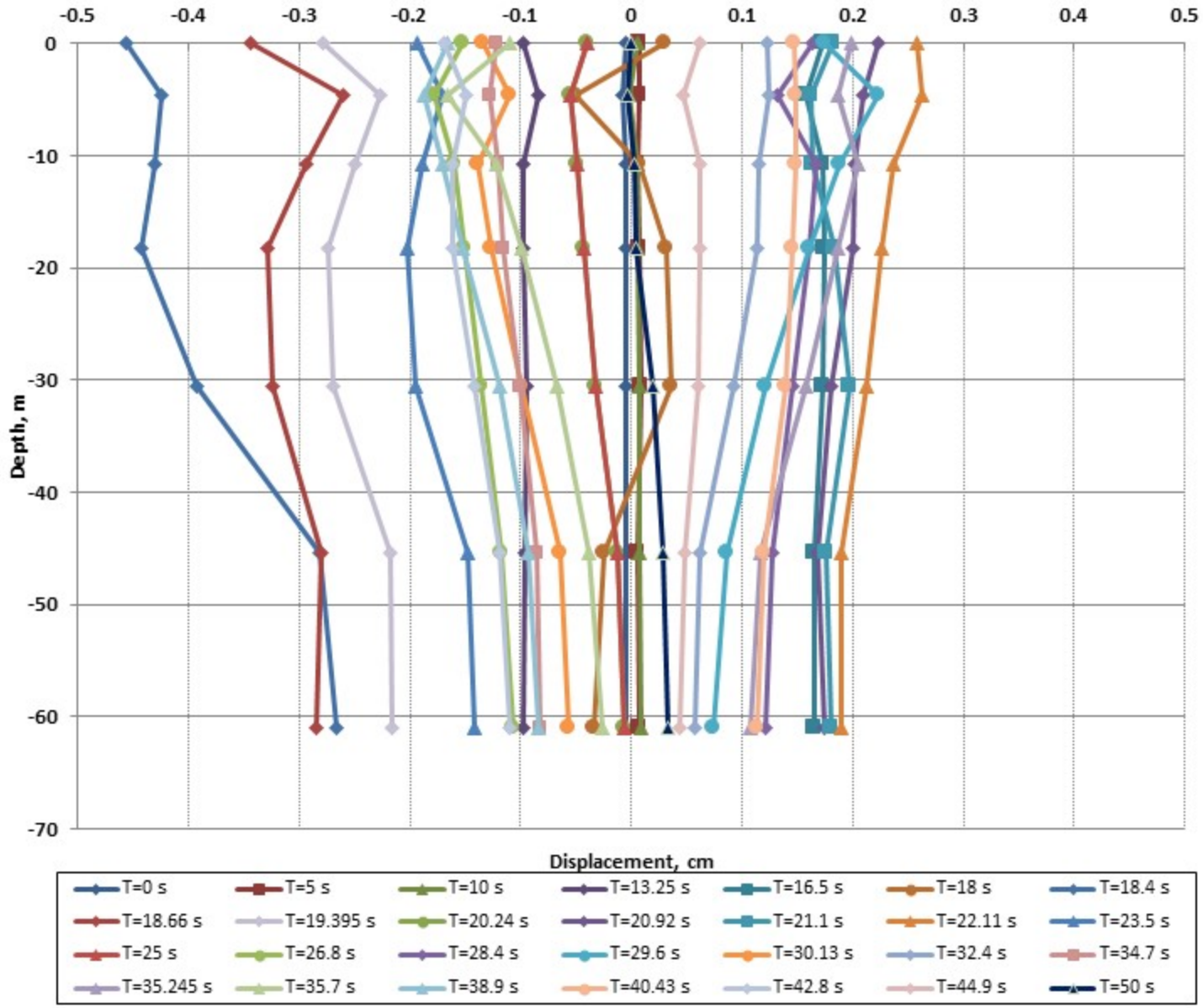

M7.0 HNN Downhole Deformation
0
-10
-20
-30
-40
-50
-60
Depth, m
-0.01
-0.005
0
0.005
0.01
Deformation, rad
T=0
T=10 s
T=15 s
T=22.6
T=24 s
T=24.7 s
T=26.0 s
T=27.55 s
T=28 s
T=28.7 s
T=30 s
T=32 s
T=35.2 s
T=36.6 s
T=37.3
T=37.9
T=40 s
T=40.6 s
T=41.8 s
T=45 s
T=48 s
T=50 s

Maximum Deformation, Acceleration, Velocity and Displacement Decay

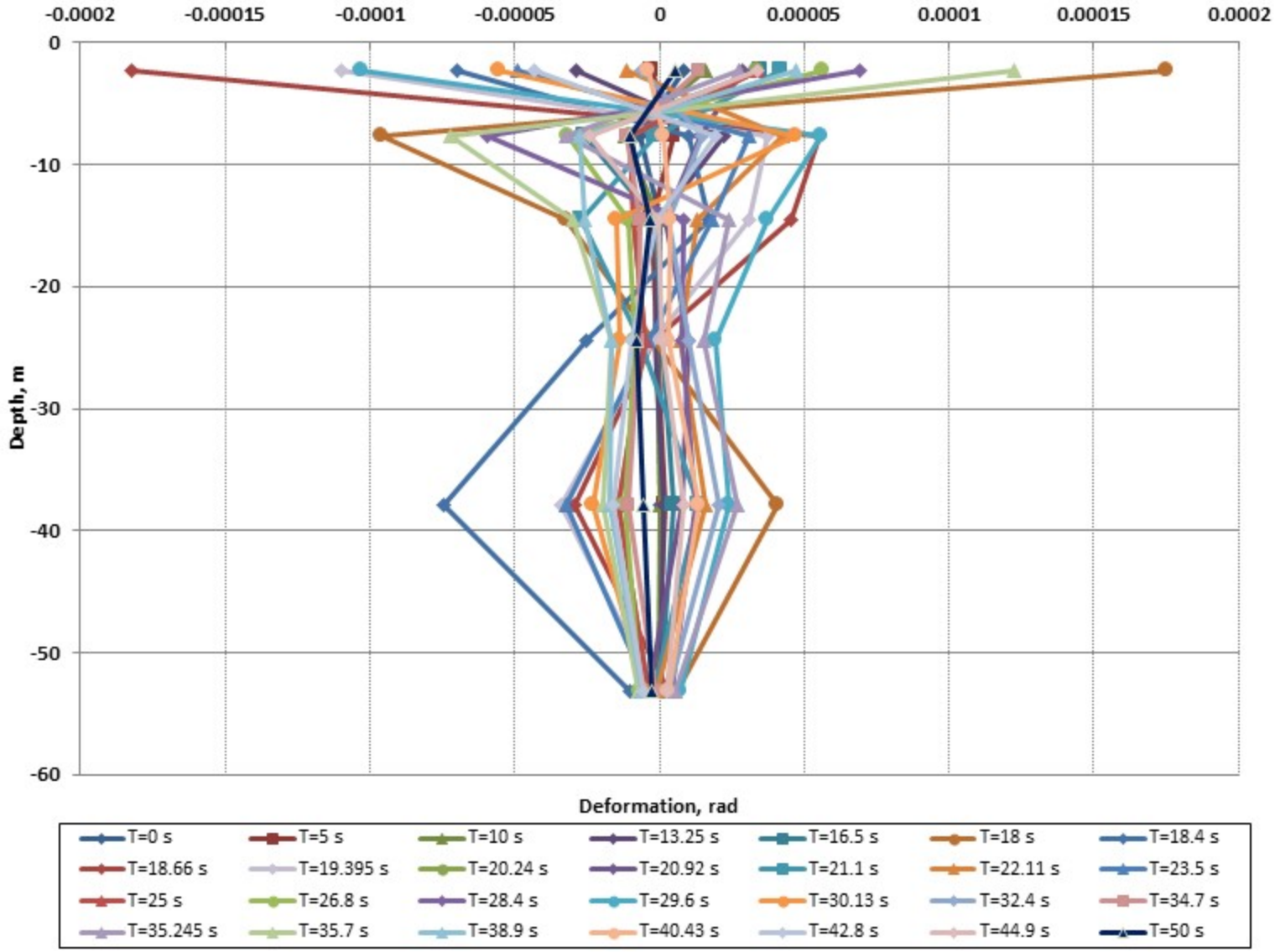




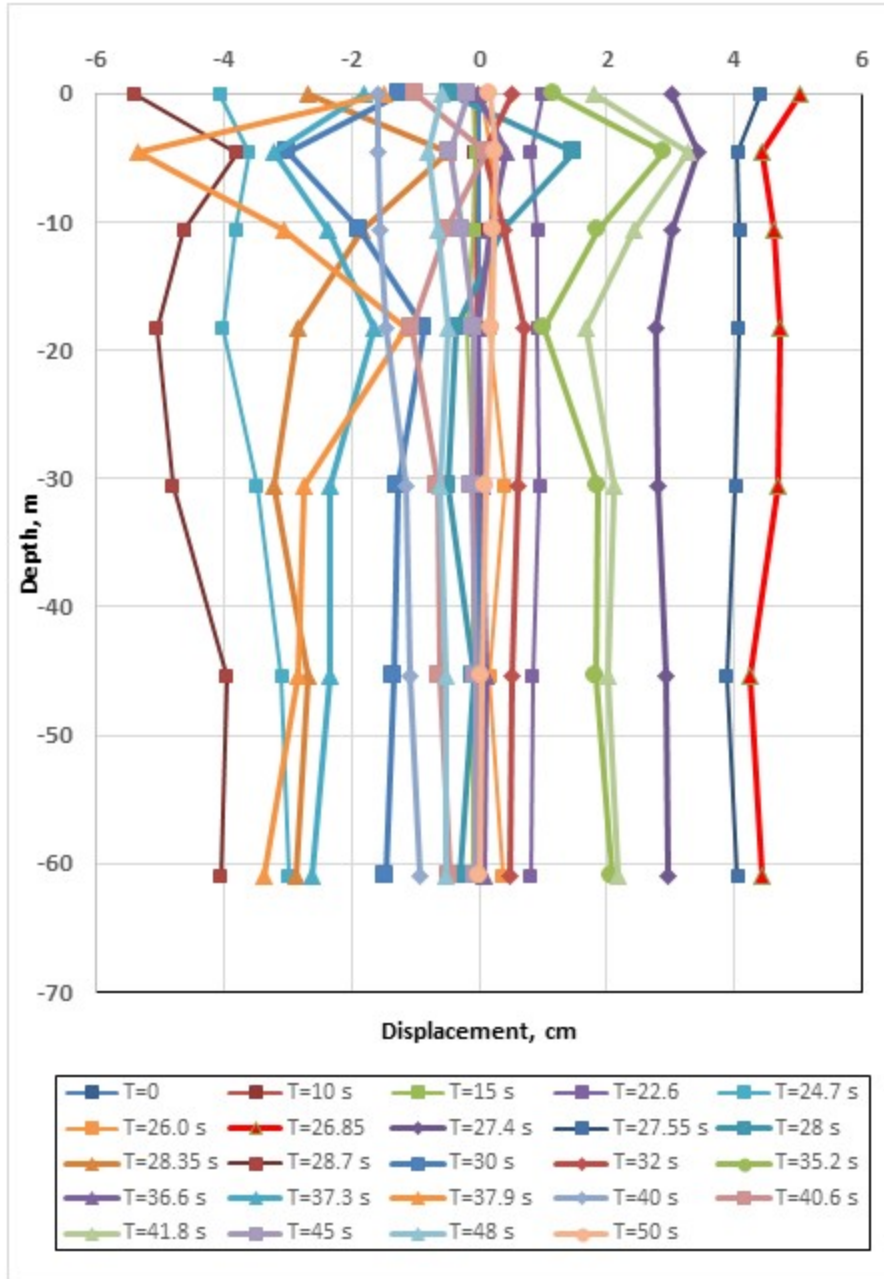
M5.7 Downhole Displacements

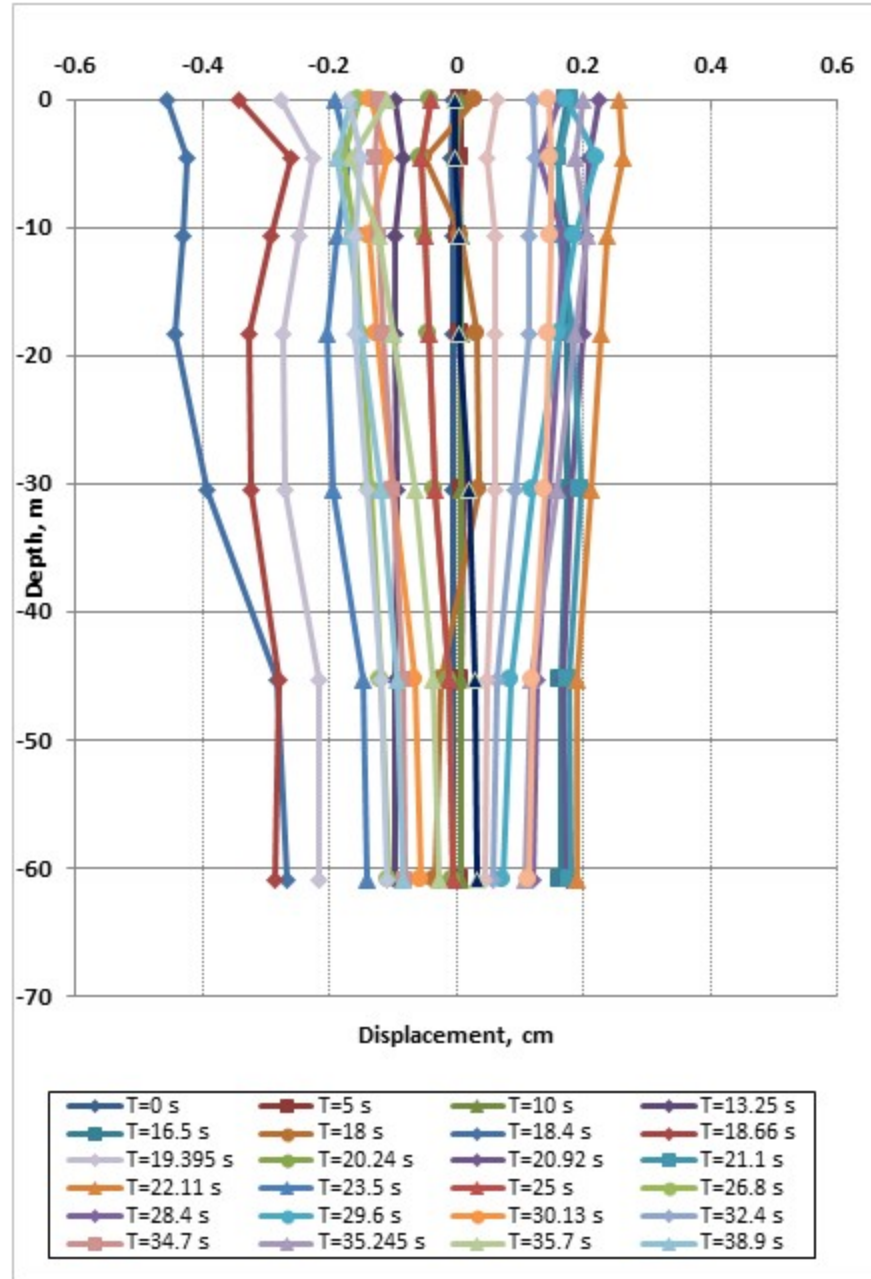


M5.7 Downhole Deformations

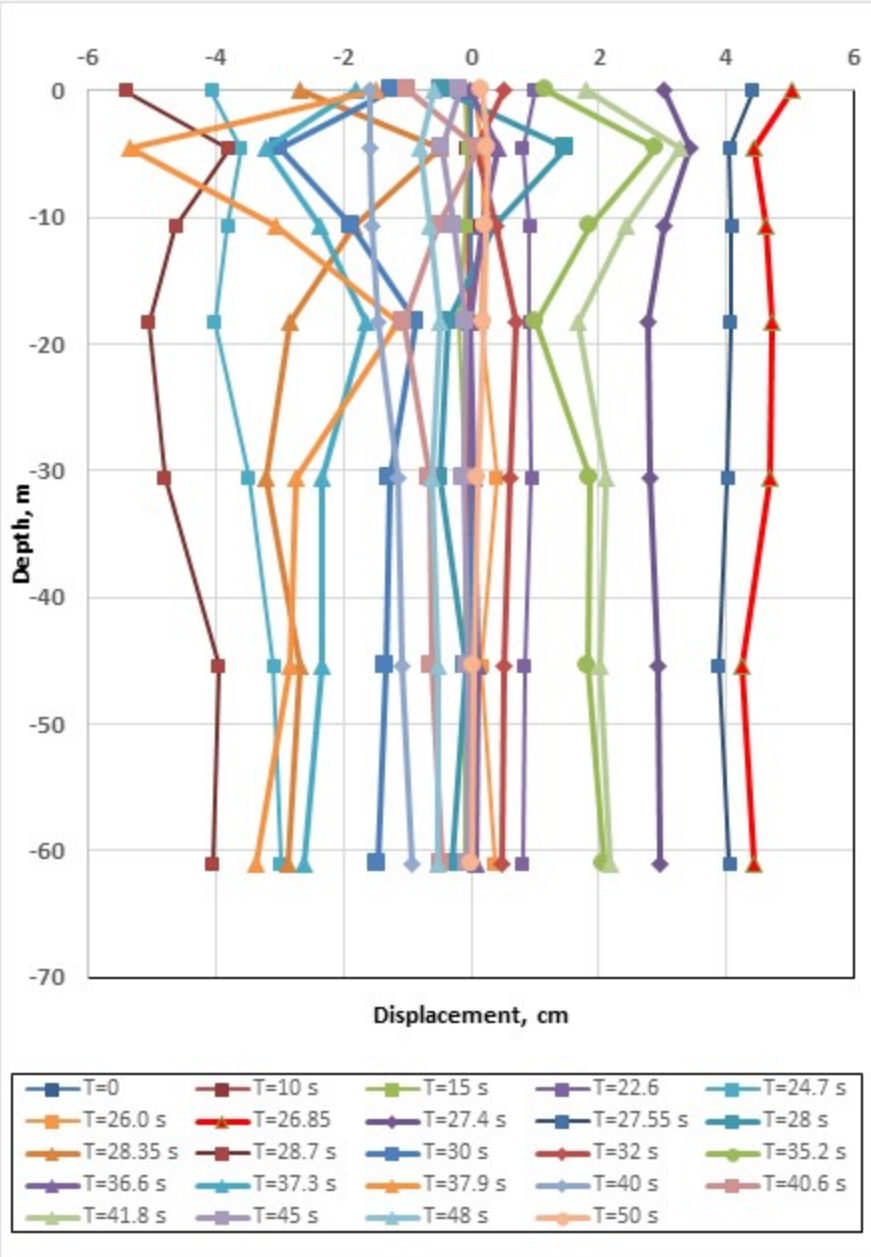


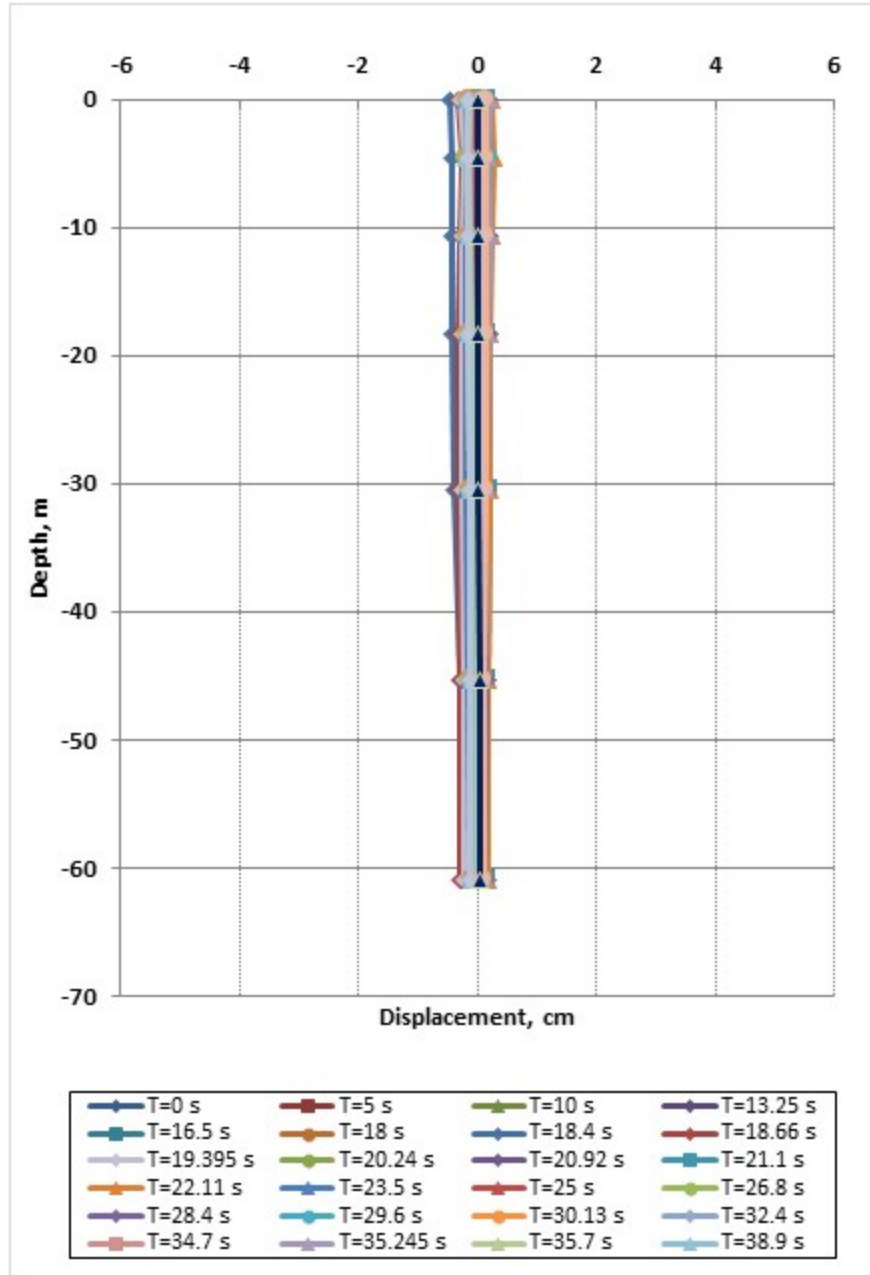
M7.0 Displacements M5.7



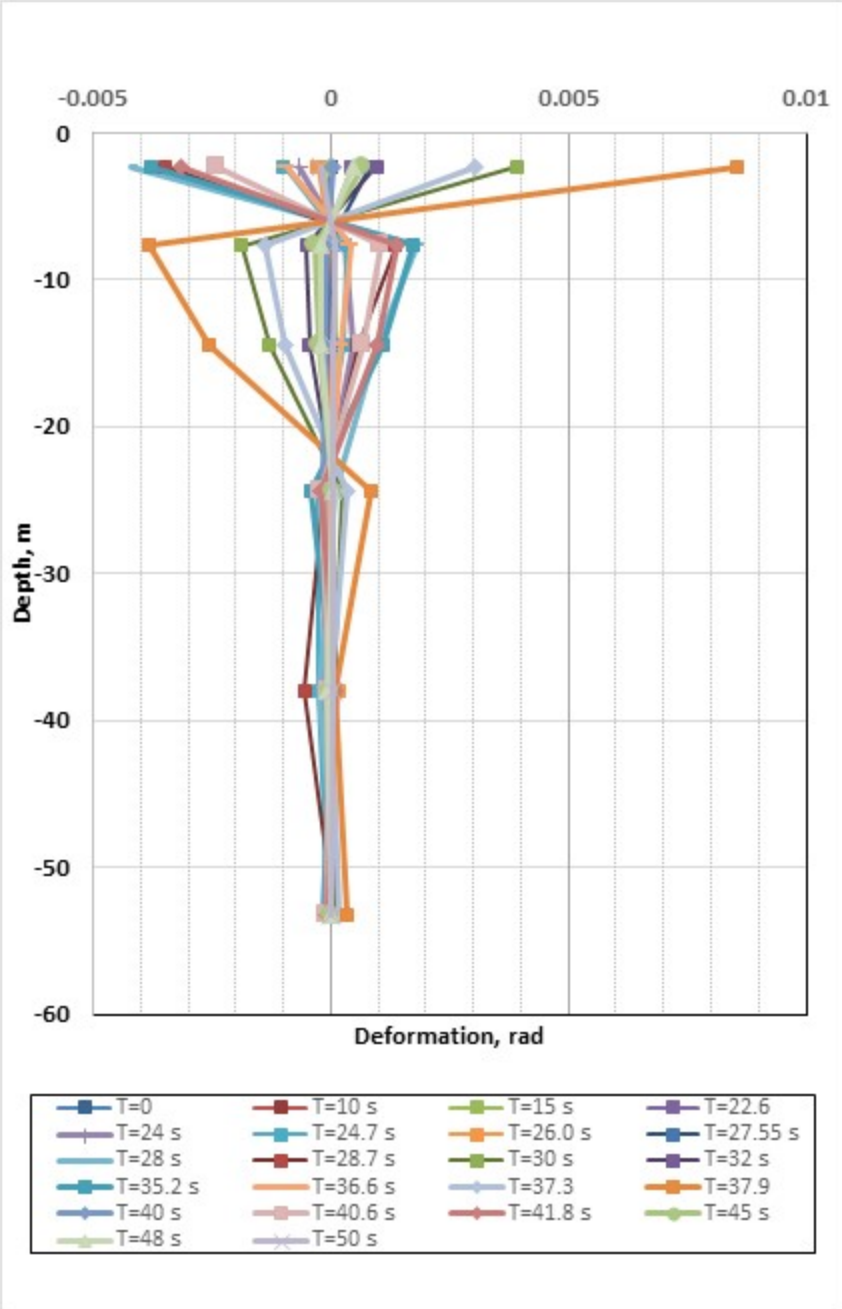


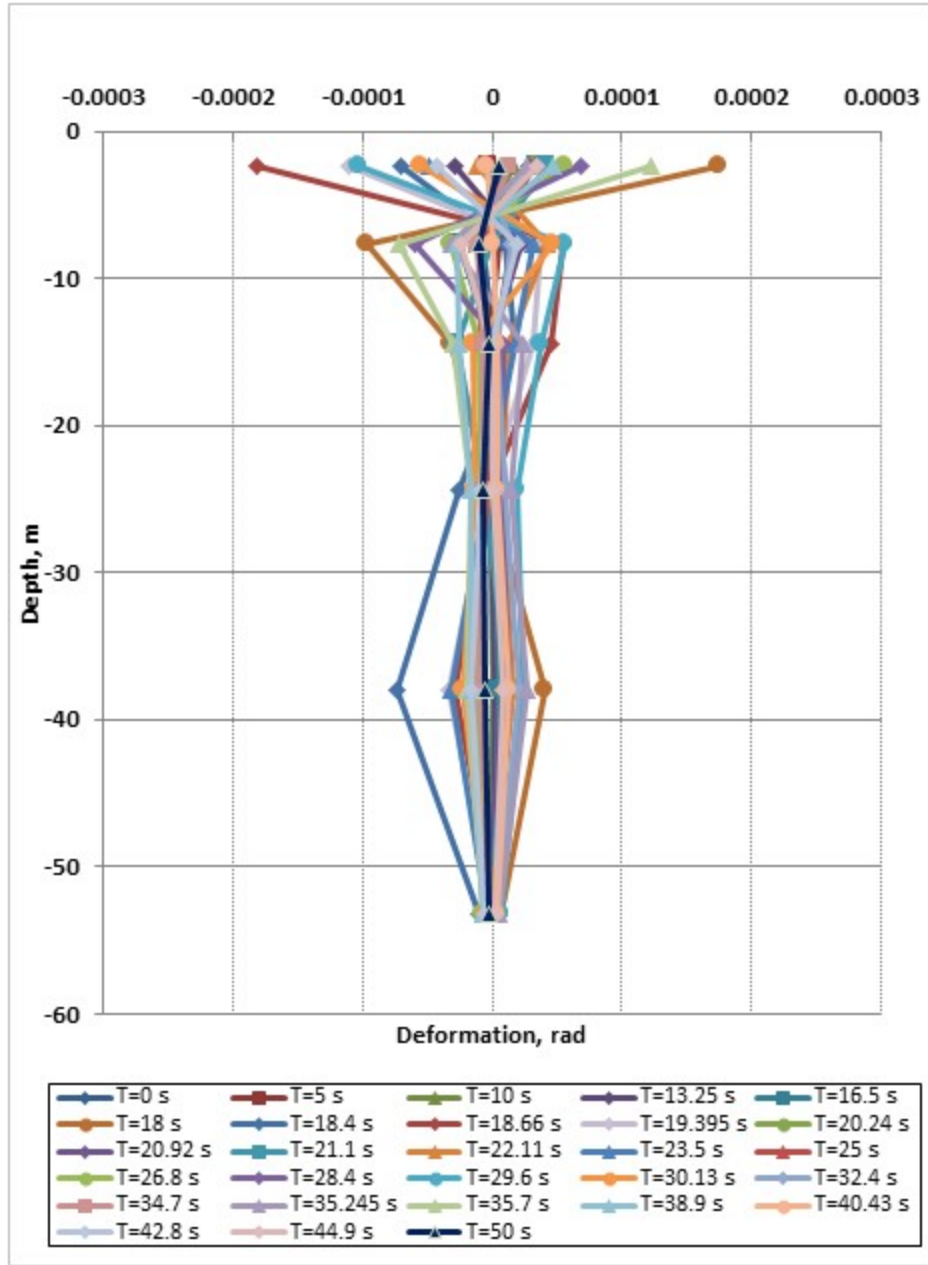
M7.0 Displacements M5.7



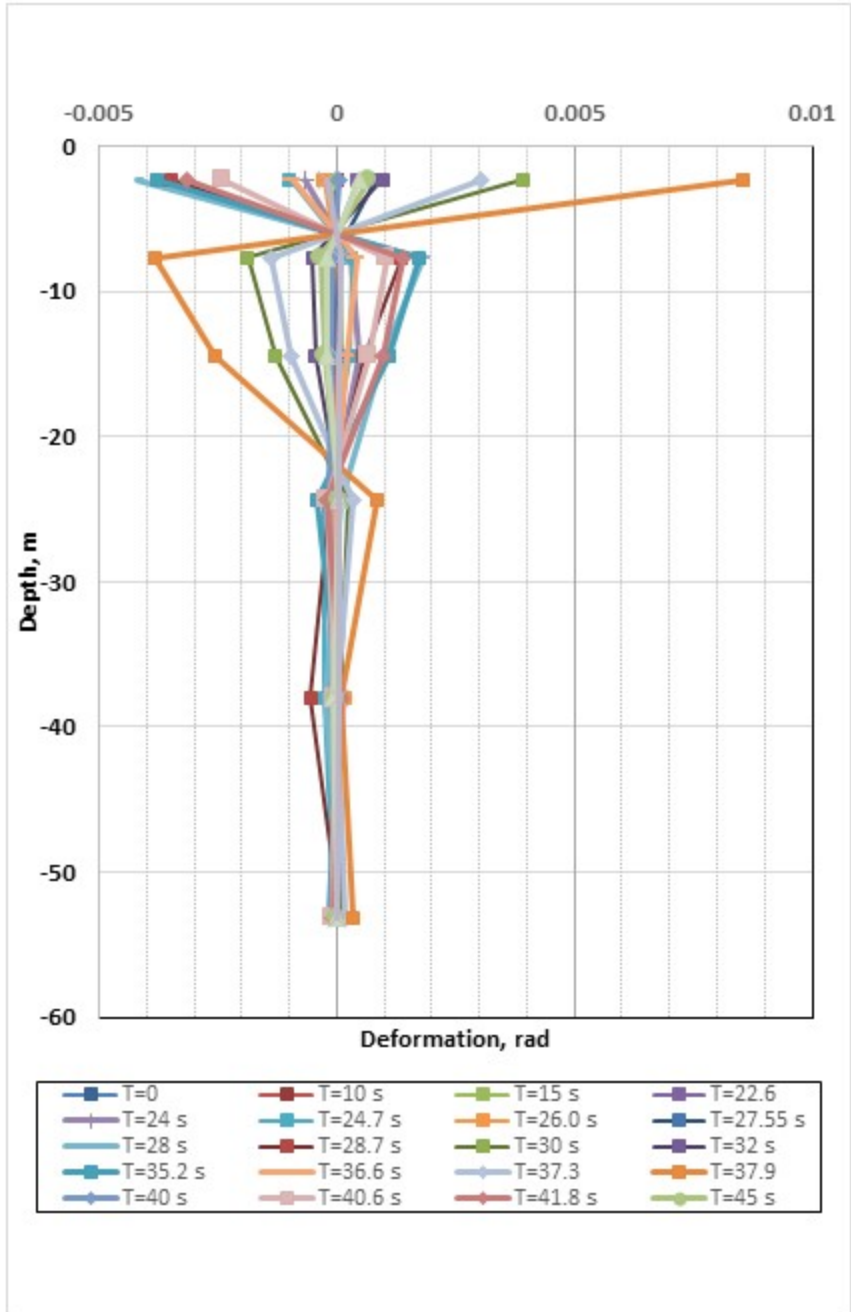


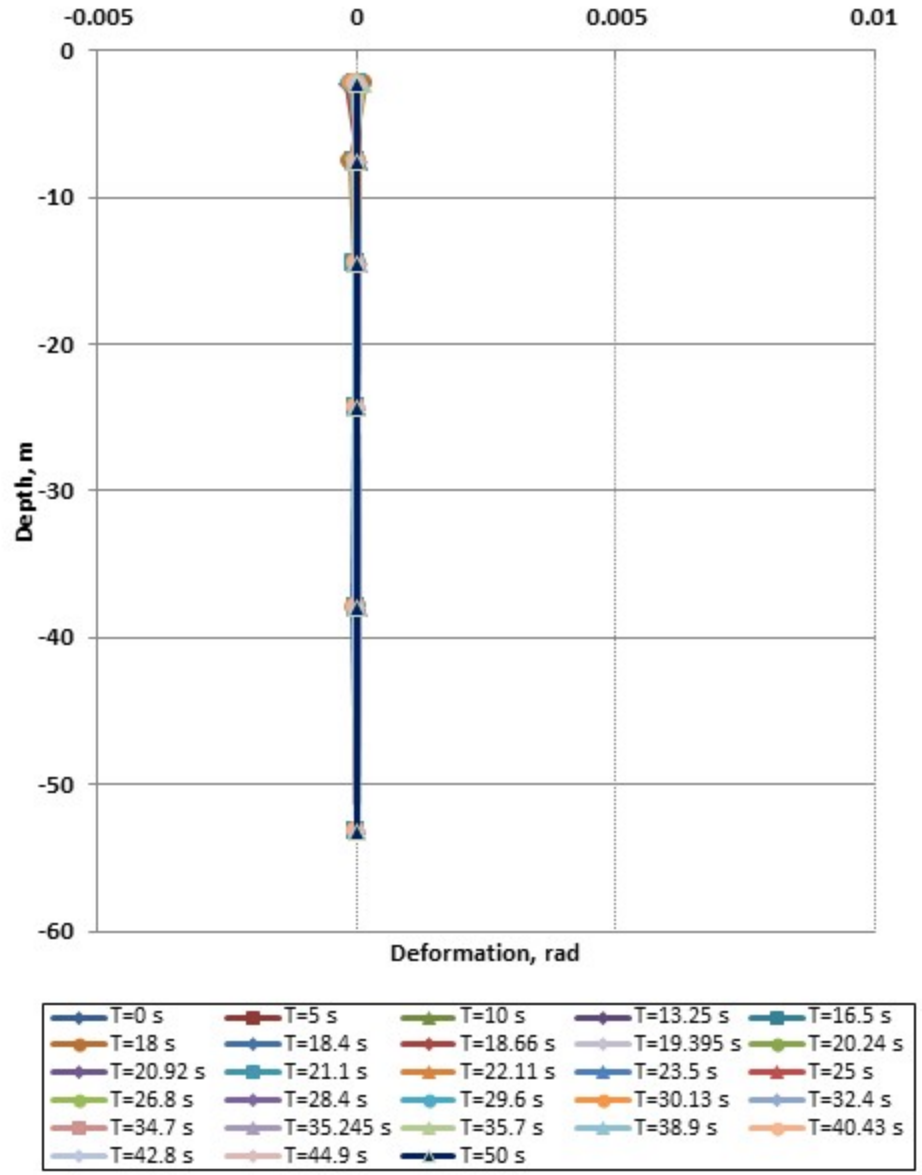
M7.0 Deformations M5.7



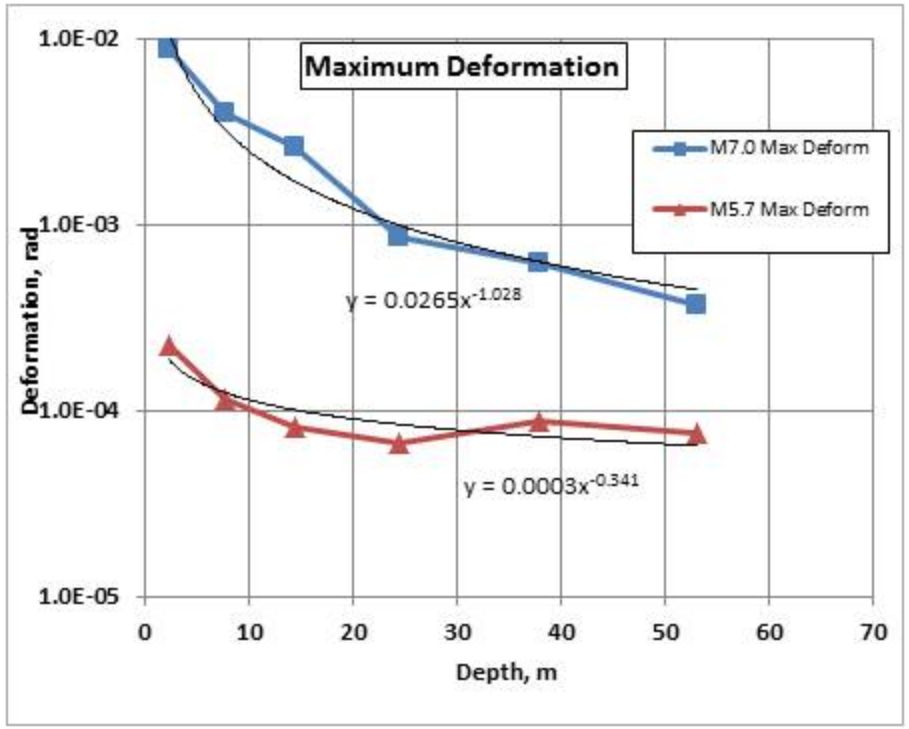


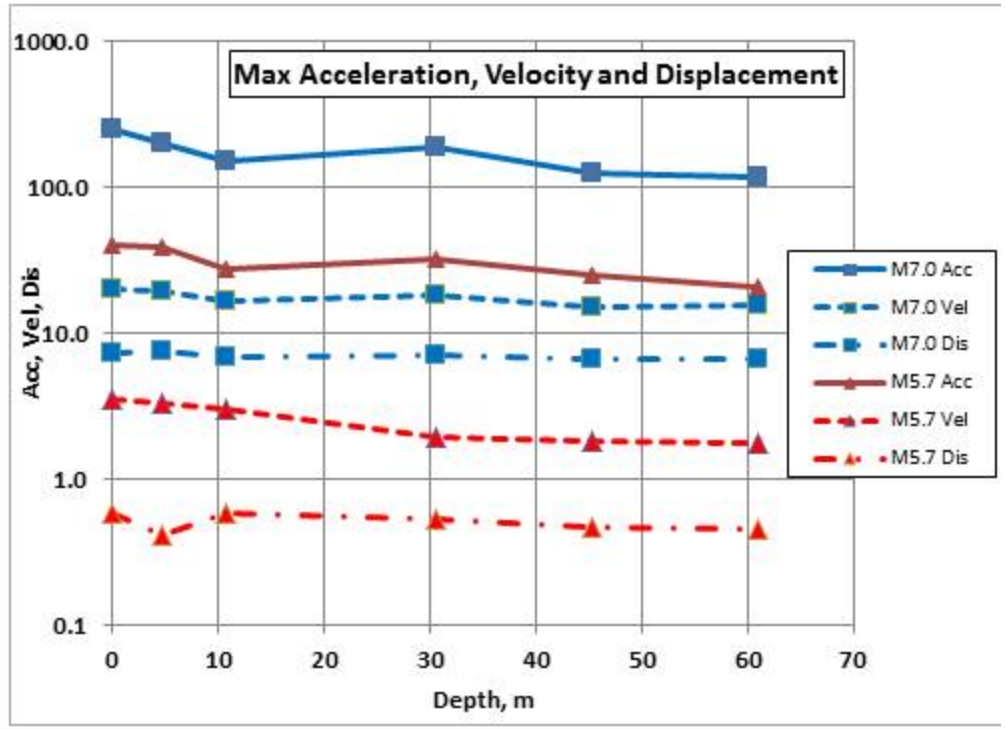
M7.0 Deformations M5.7





Comparison of Deformation and PGA, PGV and PGD Decay with Depth



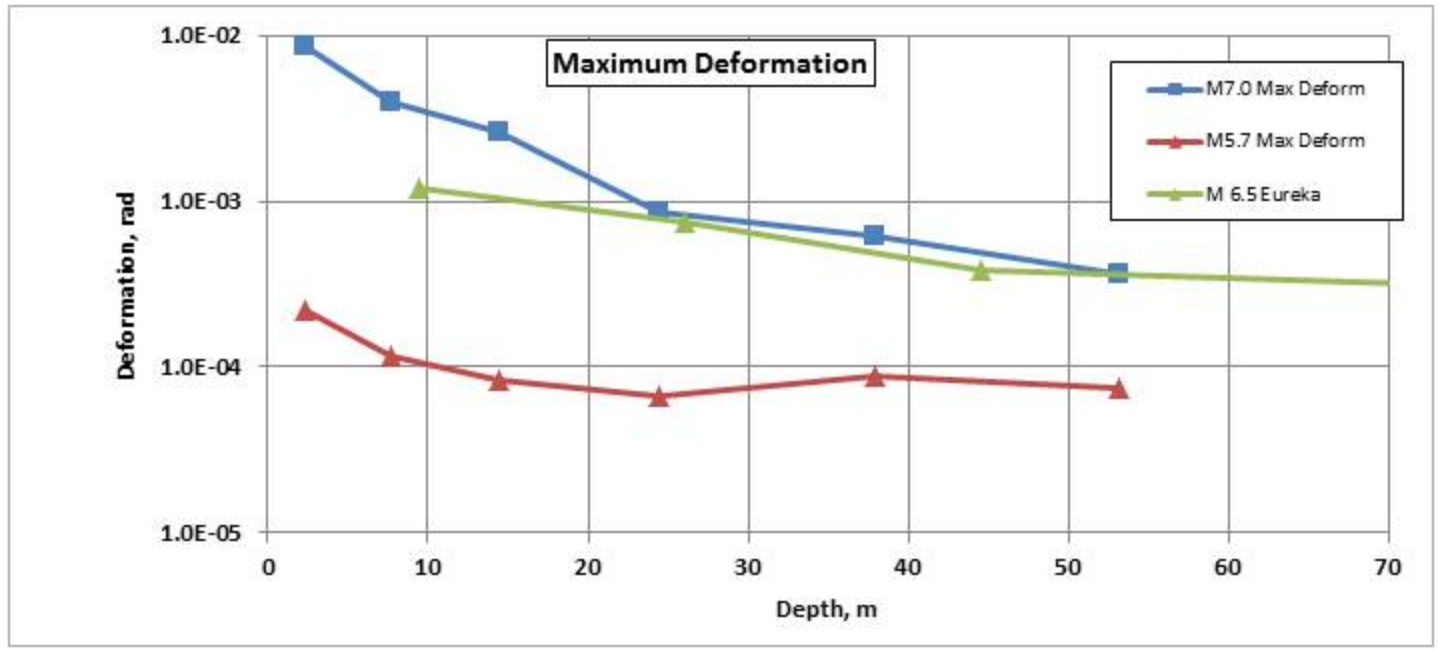


Deformation decays faster with depth than PGA, PGV and PGD.

Maximum Deformations at Depths

Delaney Array	D0-D1 (2.3 m)	D2-D1 (7.6 m)	D3-D2 (14.5 m)	D4-D3 (24.4 m)	D5-D4 (38 m)	D6-D5 (53.2 m)
M7.0	8.70E-03	3.96E-03	2.61E-03	8.67E-04	6.14E-04	3.66E-04
M5.7	2.23E-04	1.16E-04	8.26E-05	6.74E-05	8.76E-05	7.50E-05

Eureka Array	9.5 m	26 m	44.5 m	96 m
1/10/2010 M6.5, R=54 km	1.20E-03	7.60E-04	3.90E-04	2.70E-04



Concluding Remarks

- Data recorded by downhole arrays with sensors installed at different depths and geologic layers provide important information to study site amplification and other site effects.
- Downhole arrays' recordings obtained during a number of recent earthquakes provide an opportunity to estimate deformation, shear and rotational component of ground motion, and apparently were not previously used for this purpose.
- High dynamic range, synchronized and properly oriented array instrumentation is necessary for reliable calculation of deformations.
- Very large deformations are calculated based on strong-motions at the DPK array during the 2018 **M**7 Anchorage Alaska earthquake. Such large deformations suggest non-linearity at soft soil layers.


Thanks …