Appendix- A

Calculation Notes

Step-1

The experimental data was recorded for Lateral load and Horizontal displacement. These two values were logged in Data cell logger:

1. Load Cell Value –A
2. Displacement value –B

Step-2.

Calibration of the Load Cell was done and calibrations equation were developed. The Load value in Kg was noted through the calibration equations as given below:

Load Cell value obtained from test	----- Say A
Used equation: (47499 x A) + 4432	----- Say M
Load Calculation: M- (-206.61)	----- Say N
Load Value in kgs	----- N

Step-3.

Displacement Value was noted in mm ----- Say B

Step-4.

Graph were plotted between N & B on Igor Pro to draw hysteresis Loops with the values in Kgs for Lateral Load and mm for Lateral displacement.

Step-5.

The Kgs were converted into Kips by using Conversion factor:

1 Kg = 0.0022046226 Kip

The Displacement-B was defined in terms of the percentage of the pier height as percentage drift and was used in further analysis and development of graphs.

Step-6.

The load applied for each drift level was applied in three cycles. When the data collected was plotted each hysteresis Loop had three graphs, one for each cycle for a level of drift i.e. 0.1 %, 0.25%, 0.5%, 1%, 2%, 3%, 4% and 5%. From these loops with maximum values on both Positive and negative sides were picked. All of the hysteresis Loops for one experiment were combined in one graph and drawn at same scale.

Step-7.

The peak values of these curves were noted and backbone curves were drawn from these values. These backbone curves were exported from IGOR-PRO to Auto Cad files with the same scale.

Step-8.

This area under the curve calculated through AutoCAD software gave the Energy actually dissipated against each drift level. (Sample Drawing file is attached as figure-a)

Step-9.

Equivalent Stiffness (K_e) was calculated using Kawashima K. relation:

$$\boldsymbol{K_e} = \frac{\boldsymbol{P_{max} - P_{min}}}{\boldsymbol{U_{max} - U_{min}}}$$

Where as

P_{max} = Push Force; P_{min} = Pull Force; U_{max} = Push Displacement; U_{min} = Pull Displacement

Step-10.

Equivalent Damping was calculated using Kawashima K. relation:

$$\zeta = \frac{\Delta \mathbf{W}}{2\pi \mathbf{W}}$$

where as $$W = \frac{K_e}{2}(U_{max}^2 + U_{min}^2)$$

W = Strain Energy input to the system; K_e = Equivalent Stiffness; U_{max} = Push Displacement; U_{min} = Pull Displacement; and ΔW = Energy Dissipated in a Hysteresis loop

Appendix- B

Energy Dissipation at each Drift Value DRM-SL

Auto generated graph from Igor was exported to Autocad for area calculation under the curve. The scale in Igor was compared to that of autocad and the following calculation sheet was arranged.								
Drift Value	Area under the curve on ACAD		Scale Conversion (X-axis)	1mm drift in Experiment = mm in Acad drawing	Scale Conversion for Y-axis	1mm on Acad is 54.045 kg load in Experiment	Strain Energy with units (kg.mm)	Strain Energy (Kip. In)
0.10%	Area 1	21.7104	87.25mm on autocad=50mm on Igor graph	1.745	37mm in autocad = 2000kg	54.054054	672.5129714	0.058249
	Area 2	1.7338	do	1.745	do	54.054054	53.70711686	0.0046518
	Area 3	28.4719	do	1.745	do	54.054054	881.9608147	0.0763902
	Area 4		do	1.745	do	54.054054	0	0
							Total Strain Energy absorbed/dissipated	**0.139291**
0.25%	Area 1	126.75	87.25mm on autocad=50mm on Igor graph	1.745	37mm in autocad = 2000kg	54.054054	3926.275846	0.3400705
	Area 2	5.048	do	1.745	do	54.054054	156.3695501	0.0135438
	Area 3	122.7305	do	1.745	do	54.054054	3801.765663	0.3292861
	Area 4	0.4597	do	1.745	do	54.054054	14.23991327	0.0012334
							Total Strain Energy absorbed/ dissipated	**0.6841338**
0.50%	Area 1	531.3499	87.25mm on autocad=50mm on Igor graph	1.745	37mm in autocad = 2000kg	54.054054	16459.37892	1.4256126
	Area 2	16.03	do	1.745	do	54.054054	496.5538605	0.0430085
	Area 3	615.1055	do	1.745	do	54.054054	19053.83722	1.6503291
	Area 4	0.8671	do	1.745	do	54.054054	26.85975374	0.0023264
							Total Strain Energy absorbed/ dissipated	**3.1212766**
1.00%	**Area 1**	**1171.6038**	**87.25mm on autocad=50mm on Igor graph**	**1.745**	**37mm in autocad = 2000kg**	**54.054054**	**36292.22644**	**3.1434149**
	Area 2	**28.8735**	**do**	**1.745**	**do**	**54.054054**	**894.4009912**	**0.0774676**

	Area 3	**1350.3867**	**do**	**1.745**	**do**	**54.054054**	**41830.30125**	**3.6230897**
	Area 4	**2.35**	**do**	**1.745**	**do**	**54.054054**	**72.7948579**	**0.0063051**
							Total Strain Energy absorbed/ dissipated	**6.8502773**
2.00%	Area 1	3327.3884	mm=87.25n	1.745	37mm in autocad = 2000kg	54.054054	103070.9641	8.9273885
	Area 2	226.0865	mm=87.25n	1.745	do	54.054054	7003.376442	0.6065904
	Area 3	4046.5003	mm=87.25n	1.745	do	54.054054	125346.5593	10.856767
	Area 4	97.8127	mm=87.25n	1.745	do	54.054054	3029.898552	0.2624316
							Total Strain Energy absorbed/ dissipated	**20.653177**
3.00%	Area 1	5279.9086	87.25mm on autocad=50mm on Igor graph	1.745	37mm in autocad = 2000kg	54.054054	163553.275	14.166003
	Area 2	703.4785	do	1.745	do	54.054054	21791.32657	1.887434
	Area 3	6072.7023	do	1.745	do	54.054054	188111.277	16.29307
	Area 4	511.499	do	1.745	do	54.054054	15844.46682	1.3723526
							Total Strain Energy absorbed /dissipated	**33.71886**
4.00%	Area 1	7088.12	87.25mm on autocad=50mm on Igor graph	1.745	37mm in autocad = 2000kg	54.054054	219565.3992	19.017437
	Area 2	1402.7357	do	1.745	do	54.054054	43451.89189	3.7635422
	Area 3	7843.1693	do	1.745	do	54.054054	242954.2105	21.043236
	Area 4	1351.7505	do	1.745	do	54.054054	41872.54705	3.6267488
							Total Strain Energy absorbed/ dissipated	**47.450964**
5.00%	Area 1	8925.14	87.25mm on autocad=50mm on Igor graph	1.745	37mm in autocad = 2000kg	54.054054	276469.914	23.946165
	Area 2	2276.2058	do	1.745	do	54.054054	70508.96926	6.1070639
	Area 3	8787.284	do	1.745	do	54.054054	272199.6128	23.576297
	Area 4	2424.3466	do	1.745	do	54.054054	75097.85797	6.5045259
							Total Strain Energy absorbed/ dissipated	**60.134052**

Appendix- C

EQUIVALENT STIFFNESS OF CONTROL MODELS (6192 PSI)

Drift Level	Nominal Lateral Displacement	Nominal Lateral Displacement	Pull Force	Push Force	Pull Displacement	Push Displacement	Equivalent Stifness
			P_{min}(South)	P_{max}(North)	μ_{min}	μ_{max}	k_e
%	(mm)	(in)	(kips)	(kips)	(in)	(in)	(kips-in)
0.10%	1.92	0.076	-1.485	1.707	-0.079	0.079	20.196
0.25%	4.8	0.189	-3.086	2.620	-0.192	0.191	14.908
0.50%	9.6	0.378	-5.289	3.542	-0.382	0.390	11.440
1.00%	19.2	0.756	-7.462	5.376	-0.758	0.760	8.455
2.00%	38.4	1.512	-9.517	6.323	-1.516	1.541	5.182
3.00%	57.6	2.268	-9.415	5.729	-2.271	2.272	3.333
4.00%	76.8	3.024	-8.701	4.429	-3.084	3.031	2.147
5.00%	96	3.780	-19.417				

EQUIVALENT STIFNESS OF UNDAMAGED RETOFITTED MODELS - DOUBLE LAYERED CFRP (6192 PSI) UDRM-DL

Drift Level	Nominal Lateral Displacement	Nominal Lateral Displacement	Pull Force	Push Force	Pull Displacement	Push Displacement	Equivalent Stifness
			P_{min}(South)	P_{max}(North)	μ_{min}	μ_{max}	k_e
%	(mm)	(in)	(kips)	(kips)	(in)	(in)	(kips-in)
0.10	1.92	0.076	-2.064	1.510	-0.079	0.078	22.839
0.25	4.8	0.189	-4.020	2.383	-0.191	0.192	16.703
0.50	9.6	0.378	-6.012	4.634	-0.382	0.470	12.502
1.00	19.2	0.756	-8.182	6.568	-0.759	0.759	9.716
2.00	38.4	1.512	-8.624	7.596	-1.517	1.524	5.334
3.00	57.6	2.268	-8.507	7.521	-2.269	2.276	3.526
4.00	76.8	3.024	-11.246	7.104	-3.031	3.054	3.016
5.00	96	3.780					

EQUIVALENT STIFNESS OF UNDAMAGED RETOFITTED MODELS - SINGLE LAYERED CFRP (6192 PSI) UDRL-SL

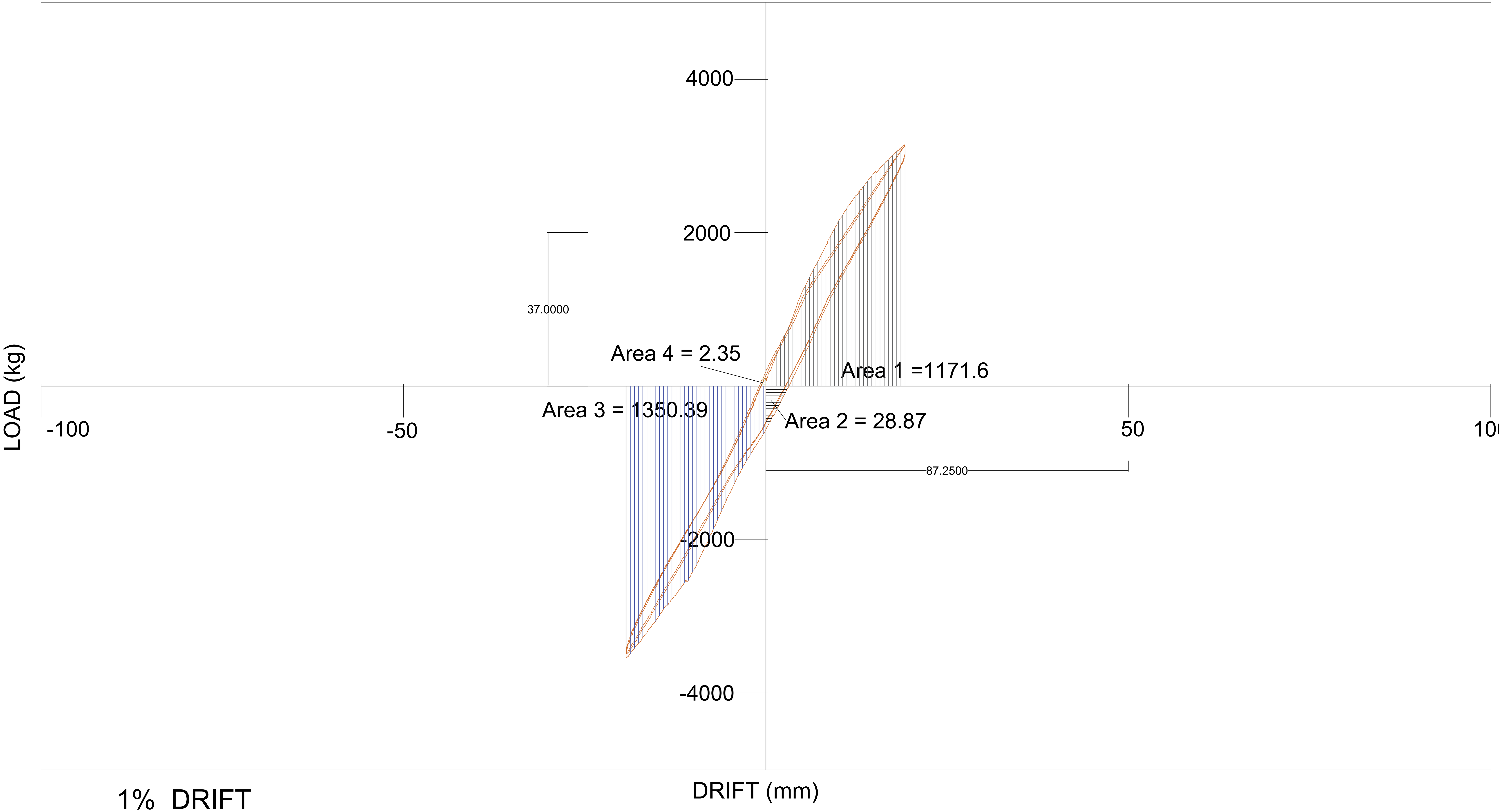
Drift Level	Nominal Lateral Displacement	Nominal Lateral Displacement	Pull Force	Push Force	Pull Displacement	Push Displacement	Equivalent Stifness
			P_{min}(South)	P_{max}(North)	μ_{min}	μ_{max}	k_e
%	(mm)	(in)	(kips)	(kips)	(in)	(in)	(kips-in)
0.10	1.92	0.076	-1.587	1.345	-0.079	0.078	18.739
0.25	4.8	0.189	-3.089	2.863	-0.191	0.192	15.525
0.50	9.6	0.378	-4.970	4.213	-0.382	0.470	10.784
1.00	19.2	0.756	-7.413	6.361	-0.759	0.759	9.074
2.00	38.4	1.512	-9.866	7.799	-1.517	1.524	5.809
3.00	57.6	2.268	-8.659	7.702	-2.269	2.276	3.600
4.00	76.8	3.024	-7.453	6.734	-3.031	3.054	2.332
5.00	96	3.780	-13.001				

EQUIVALENT STIFNESS OF DAMAGED RETOFITTED MODELS - DOUBLE LAYERED CFRP (6192 PSI) DRM-DL

Drift Level	Nominal Lateral Displacement	Nominal Lateral Displacement	Pull Force	Push Force	Pull Displacement	Push Displacement	Equivalent Stifness
			P_{min}(South)	P_{max}(North)	μ_{min}	μ_{max}	k_e
%	(mm)	(in)	(kips)	(kips)	(in)	(in)	(kips-in)
0.10	1.92	0.076	-1.517	0.860	-0.077	0.087	14.552
0.25	4.8	0.189	-2.893	1.805	-0.191	0.190	12.327
0.50	9.6	0.378	-5.081	3.351	-0.381	0.379	11.089
1.00	19.2	0.756	-8.145	4.994	-0.758	0.757	8.675
2.00	38.4	1.512	-10.600	6.669	-1.514	1.542	5.652
3.00	57.6	2.268	-10.614	6.467	-2.271	2.276	3.756
4.00	76.8	3.024	-9.704	5.533	-3.025	3.039	2.512
5.00	96	3.780					

EQUIVALENT STIFNESS OF DAMAGED RETOFITTED MODELS - SINGLE LAYERED CFRP (6192 PSI) DRM-SL

Drift Level	Nominal Lateral Displacement	Nominal Lateral Displacement	Pull Force	Push Force	Pull Displacement	Push Displacement	Equivalent Stifness
			P_{min}(South)	P_{max}(North)	μ_{min}	μ_{max}	k_e
%	(mm)	(in)	(kips)	(kips)	(in)	(in)	(kips-in)
0.10	1.92	0.076	-1.537	1.197	-0.077	0.087	16.736
0.25	4.8	0.189	-2.893	2.874	-0.191	0.190	15.133
0.50	9.6	0.378	-4.994	4.620	-0.381	0.379	12.645
1.00	19.2	0.756	-7.722	6.894	-0.758	0.757	9.650
2.00	38.4	1.512	-9.640	8.671	-1.514	1.542	5.993
3.00	57.6	2.268	-9.419	8.728	-2.271	2.276	3.991
4.00	76.8	3.024	-9.136	8.396	-3.025	3.039	2.891
5.00	96	3.780					



1%_DRIFT

DRM-SL

GRAPH-1