CONCEPT DEVELOPMENT FLOATING BRIDGE E39 BJØRNAFJORDEN

Norconsult

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1 INTRODUCTION

Eigen periods and Eigen modes of the floating bridge is calculated with frequency-dependent added mass on the pontoons. A python script is developed which uses built-in routines based on ARPACK [1] to solve the eigenvalue problem. The script was verified against the Eigenvalue solver in Sofistik [2] in phase 3 of the Bjørnafjorden project [3], for the bridge without added mass on the pontoons. The program performs an iteration loop to account for the frequency-dependent added mass to get a correct picture of the behavior of the floating bridge. The first 50 modes are reported.

Results from the Eigen value problem shows that added mass has a significant effect on the Eigen periods of the structure. Especially for Eigen periods in between 5 and 10s. The slope of the added mass curve is very steep in this area.

2 MODAL ANALYSIS

2.1 Summary of results

The first 100 Eigen periods with frequency dependent added mass included is found on olavolsen.interactive.no [4] for K12 – Model 27 and in Table 2-1.

> *Table 2-1 Eigen periods with added mass*

Mode	Frequency [Hz]	Period [s]		Mode	Frequency [Hz]	Period [s]
1	0.0179	55.9		51	0.2239	4.47
2	0.0204	48.97		52	0.2313	4.32
3	0.0316	31.68		53	0.232	4.31
4	0.0474	21.09		54	0.2361	4.24
5	0.0633	15.81		55	0.2396	4.17
6	0.0772	12.96		56	0.2461	4.06
7	0.0875	11.43		57	0.2499	4
8	0.1035	9.66		58	0.2522	3.96
9	0.1141	8.76		59	0.2549	3.92
10	0.1276	7.84		60	0.2622	3.81
11	0.1358	7.36		61	0.2662	3.76
12	0.1445	6.92		62	0.2671	3.74
13	0.1456	6.87		63	0.2752	3.63
14	0.1486	6.73		64	0.2794	3.58
15	0.151	6.62		65	0.2833	3.53
16	0.1521	6.57		66	0.2846	3.51
17	0.1533	6.52		67	0.2904	3.44
18	0.1565	6.39		68	0.2916	3.43
19	0.1569	6.37		69	0.2944	3.4
20	0.1589	6.29		70	0.2996	3.34
21	0.1592	6.28		71	0.3014	3.32

Mode	Frequency [Hz]	Period [s]		Mode	Frequency [Hz]	Period [s]
22	0.1612	6.2		72	0.3029	3.3
23	0.1613	6.2		73	0.3068	3.26
24	0.1613	6.2		74	0.3165	3.16
25	0.1613	6.2		75	0.3258	3.07
26	0.1615	6.19		76	0.3366	2.97
27	0.1617	6.19		77	0.3461	2.89
28	0.1624	6.16		78	0.3477	2.88
29	0.1631	6.13		79	0.3524	2.84
30	0.1643	6.09		80	0.3597	2.78
31	0.1658	6.03		81	0.3647	2.74
32	0.1676	5.97		82	0.3808	2.63
33	0.1679	5.96		83	0.3838	2.61
34	0.1701	5.88		84	0.3968	2.52
35	0.1728	5.79		85	0.4007	2.5
36	0.1748	5.72		86	0.4101	2.44
37	0.176	5.68		87	0.4178	2.39
38	0.1791	5.58		88	0.4241	2.36
39	0.1828	5.47		89	0.4408	2.27
40	0.1832	5.46		90	0.4455	2.24
41	0.1877	5.33		91	0.4483	2.23
42	0.1921	5.21		92	0.453	2.21
43	0.1963	5.09		93	0.4547	2.2
44	0.1974	5.07		94	0.4795	2.09
45	0.2007	4.98		95	0.48	2.08
46	0.2038	4.91		96	0.4951	2.02
47	0.2099	4.76		97	0.4976	2.01
48	0.2111	4.74		98	0.5028	1.99
49	0.2168	4.61		99	0.5073	1.97

Mode	Frequency [Hz]	Period [s]		Mode	Frequency [Hz]	Period [s]
50	0.2211	4.52		100	0.5078	1.97

2.1.1   Horizontal modes

The first eleven modes are horizontal Eigen modes. See mode number 5 in Figure 2-1 located at a period of 15.81s.
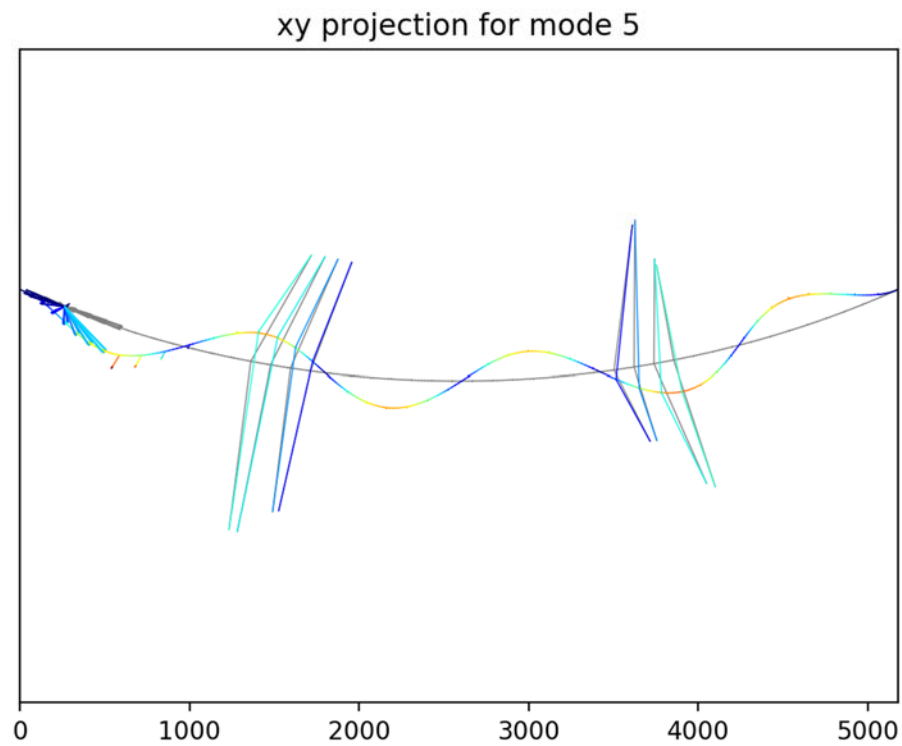
> *Figure 2-1 Fifth horizontal Eigen mode*

2.1.2   Vertical modes

Pendulum modes and vertical modes around the mooring system can be located in between 6.9 seconds and 6.3 seconds. However the first global vertical mode can be found at a period of 6.2 seconds. See mode number 22 in Figure 2-2.
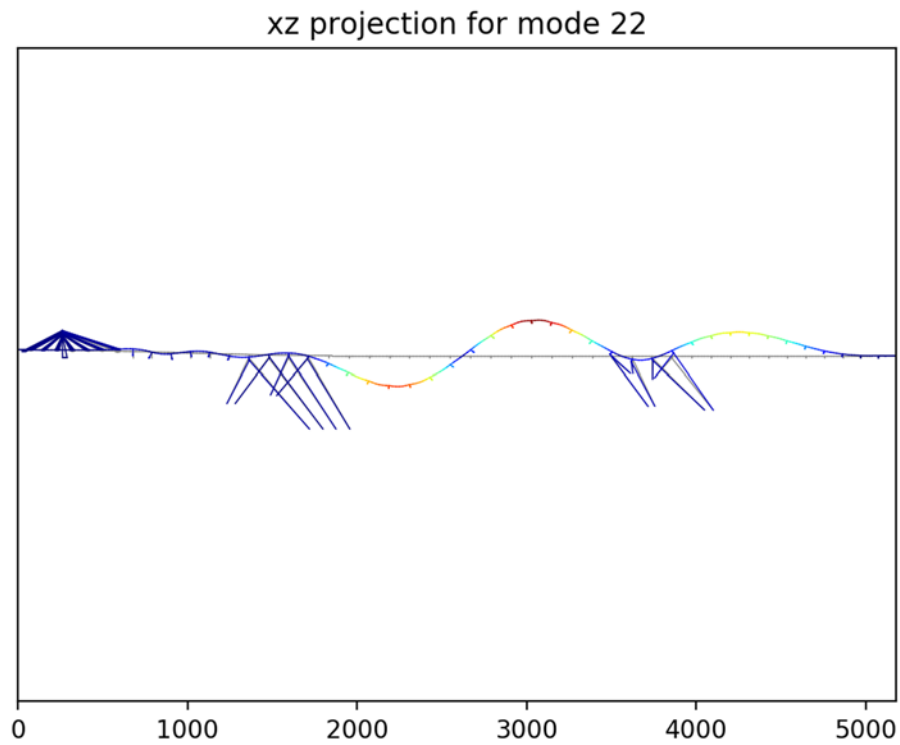
> *Figure 2-2 Global vertical mode*

2.1.3 Torsional modes

Many modes have torsional contributions. One of the first mode with a significant torsional contribution is seen at mode number 11 located at a period of 7.36s. See Figure 2-3.

iso projection for mode 11
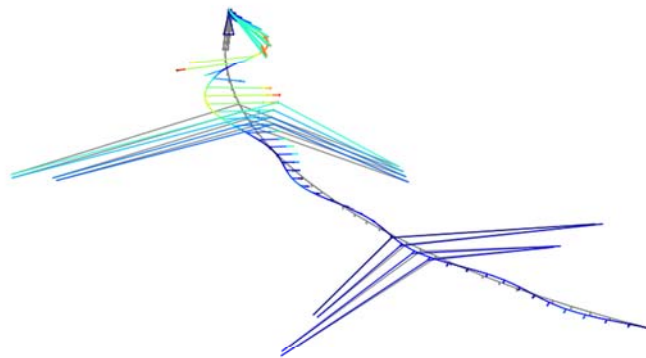
> *Figure 2-3 Torsional mode*

2.1.4   Pendulum modes on high bridge

The first pendulum mode is located at 6.92s. See Figure 2-4. These are modes that trigger high response in the highest part of the floating bridge about the weak axis of the bridge girder.
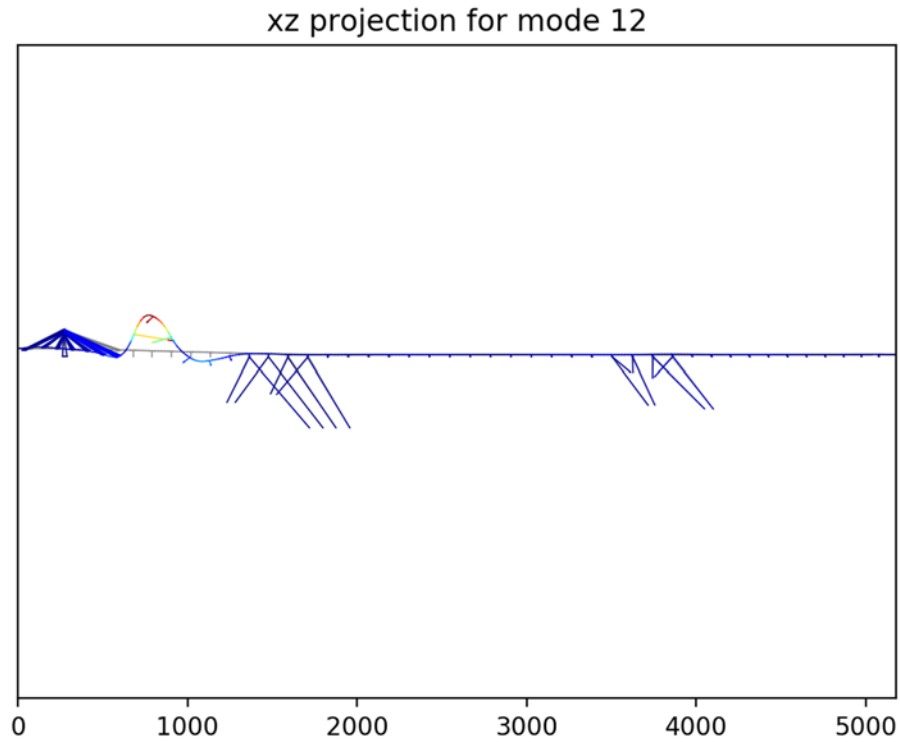
> *Figure 2-4 First pendulum mode*

2.1.5   Tower modes

The tower starts to participate already in the first pendulum modes but becomes more active in the vertical modes from about mode number 27 located at a period of 6.2s. See mode 30 in Figure 2-5.

xz projection for mode 30
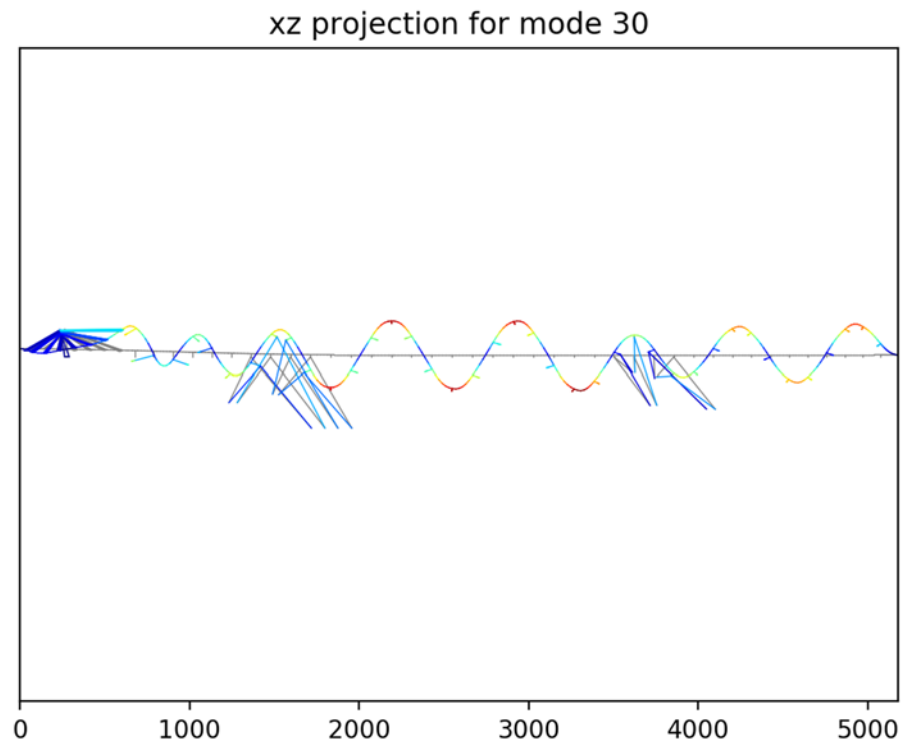
> *Figure 2-5 Mode including tower response*

2.2   Mode shapes

Mode shapes for the first 50 Eigen periods with added mass included are currently found on the website olavolsen.interactive.no for K12 – Model 27 [4] and also displayed below.

iso projection for mode 1
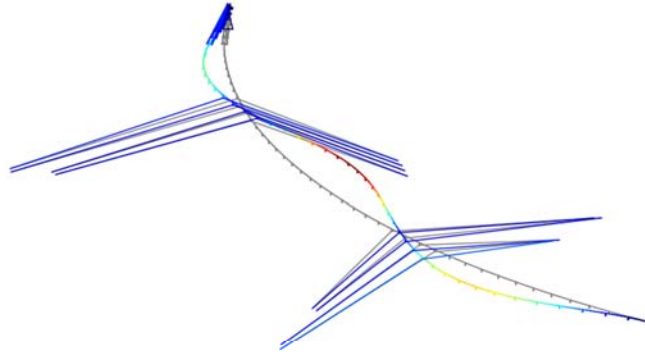
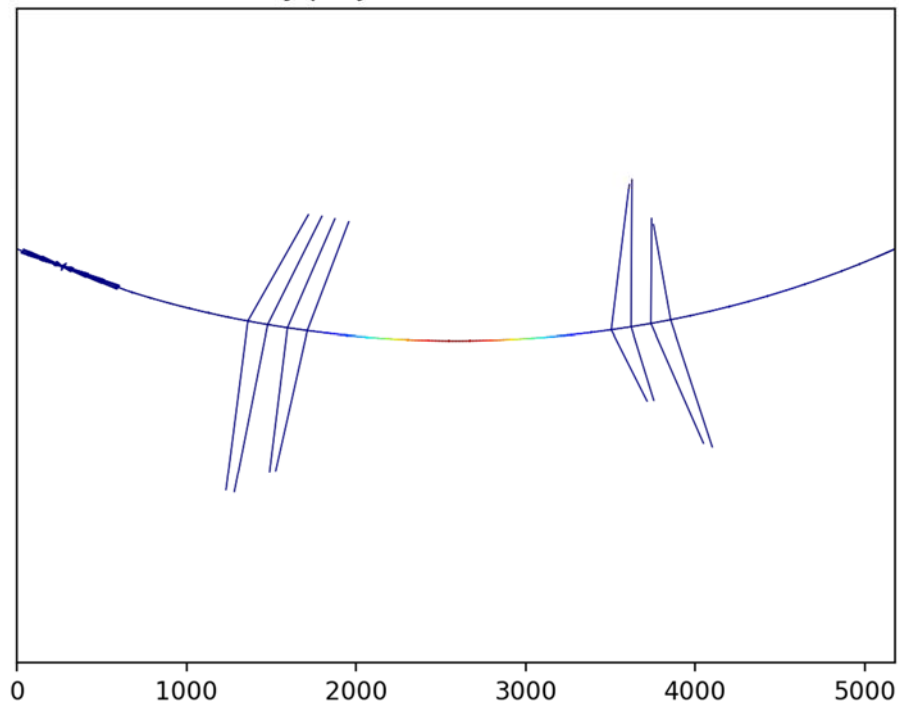xy projection for mode 1
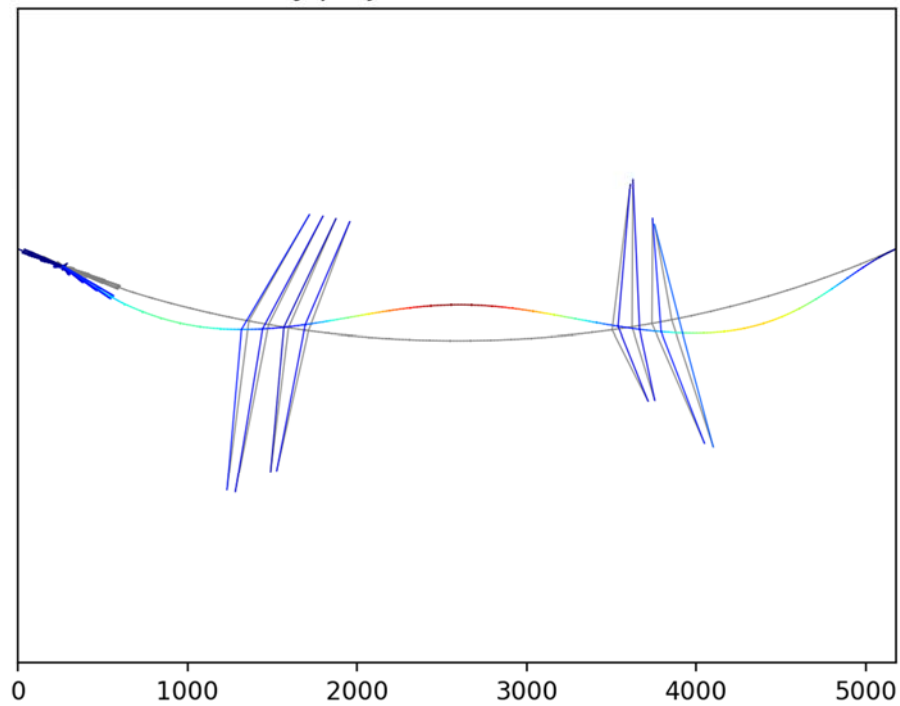
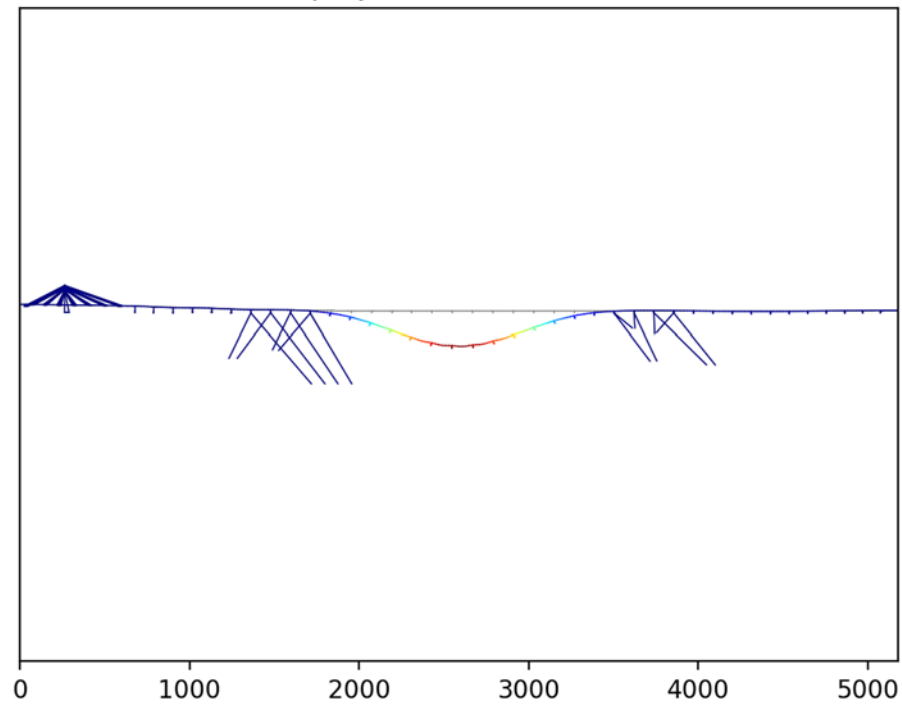## xz projection for mode 1
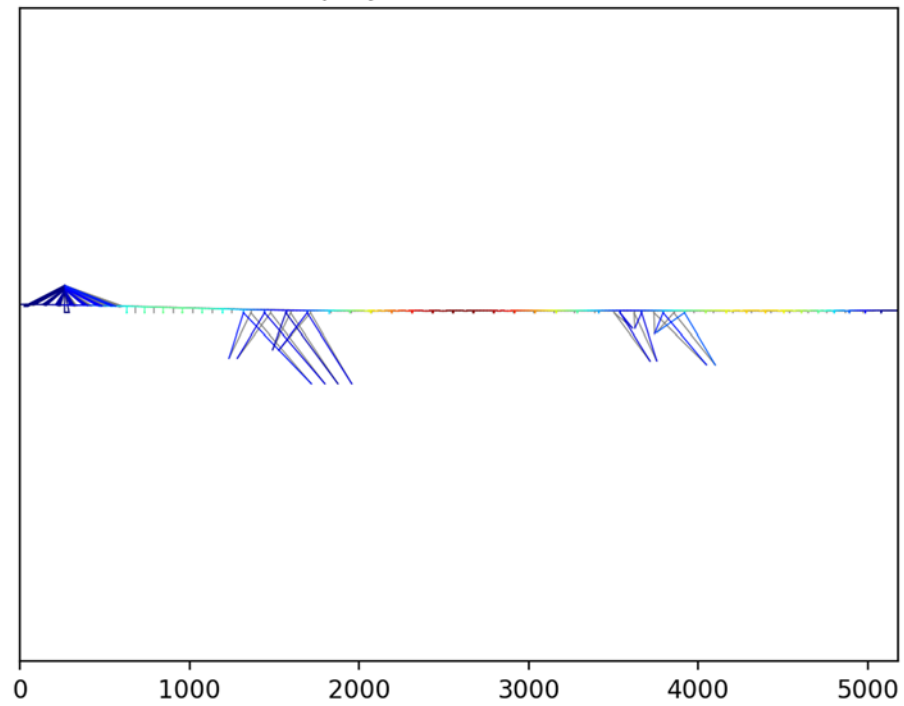
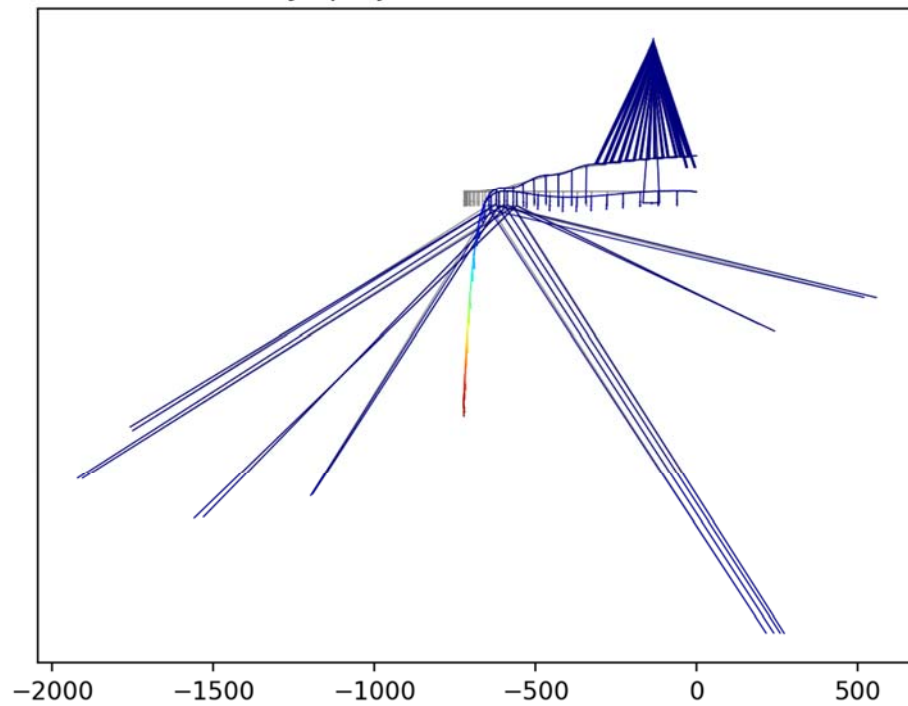## yz projection for mode 1
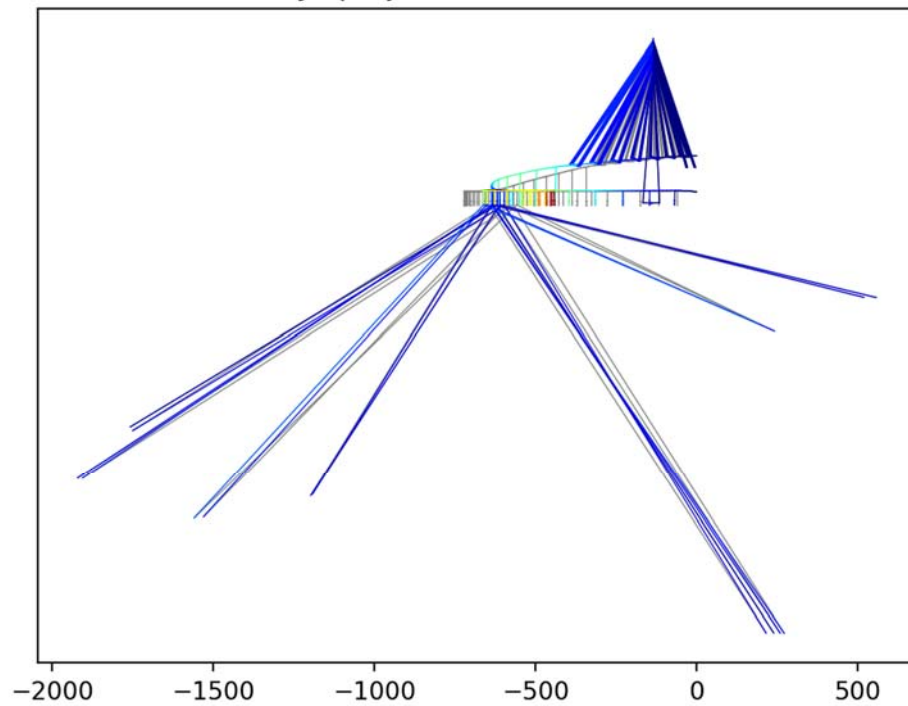
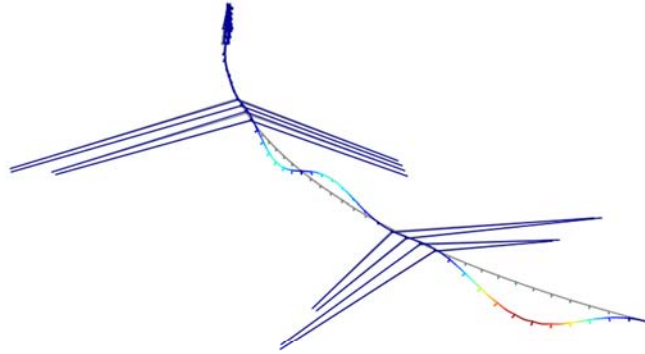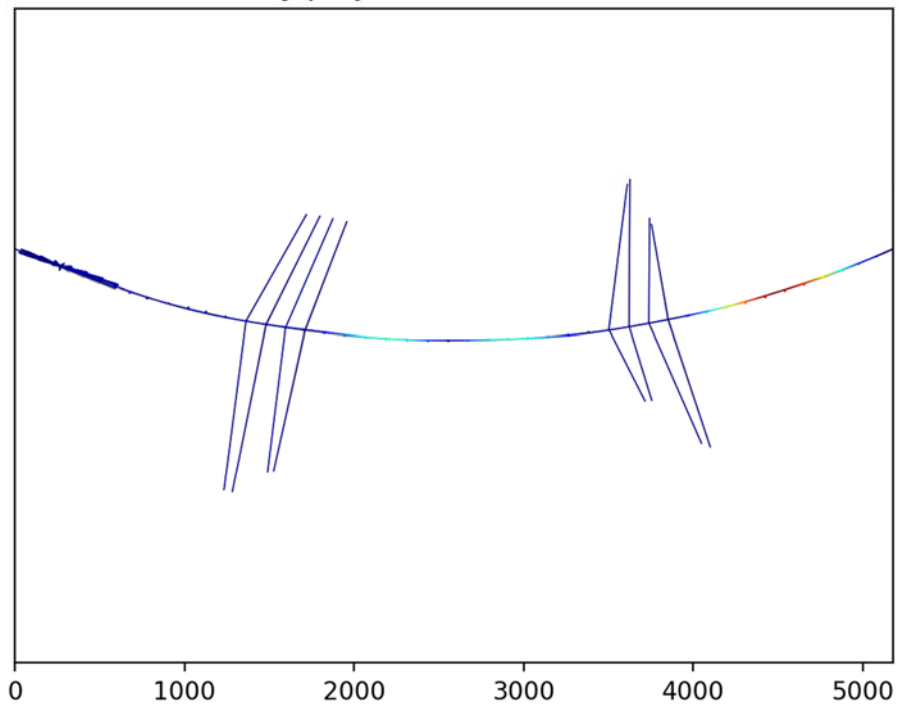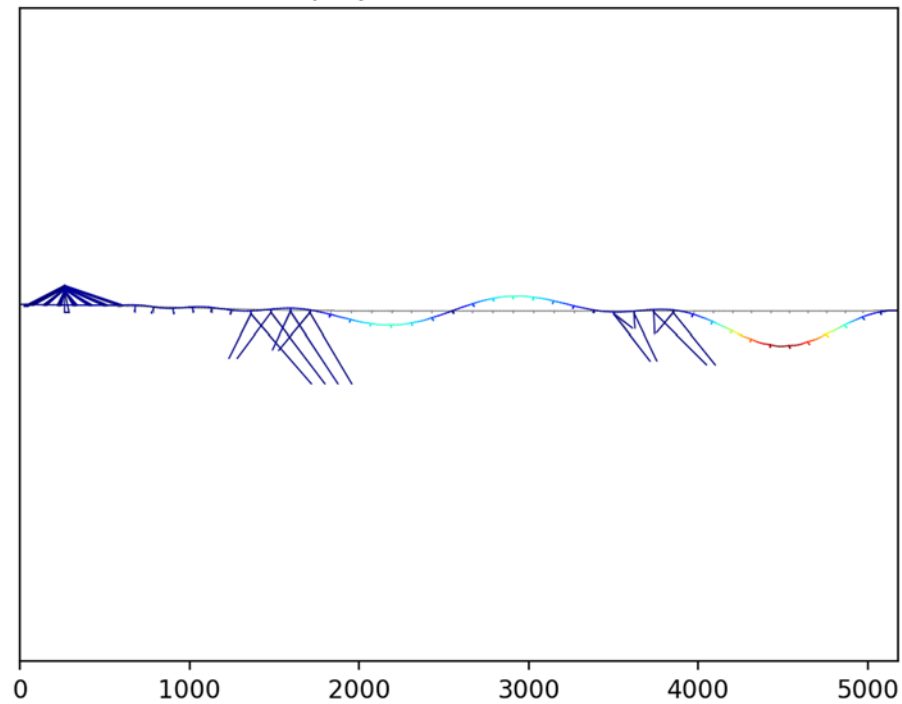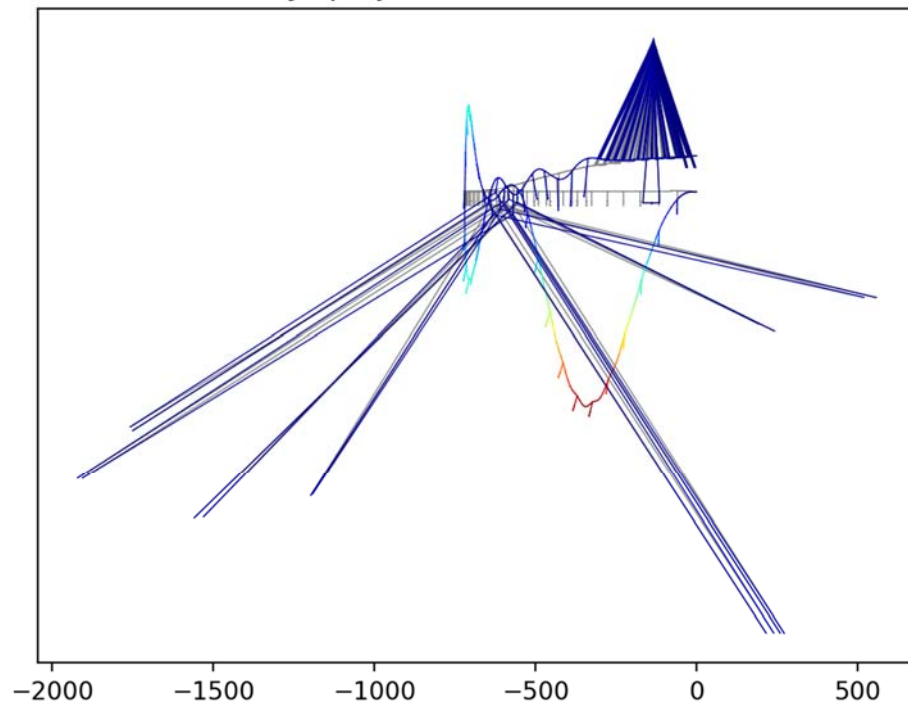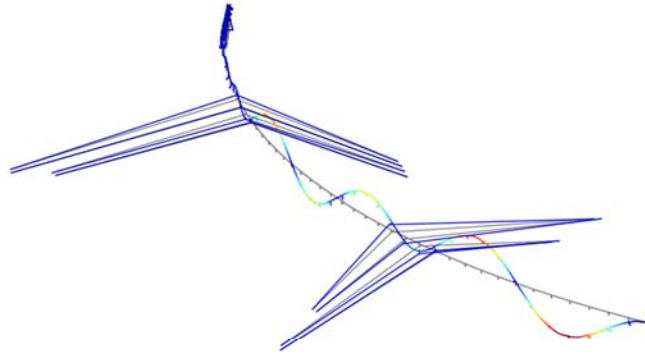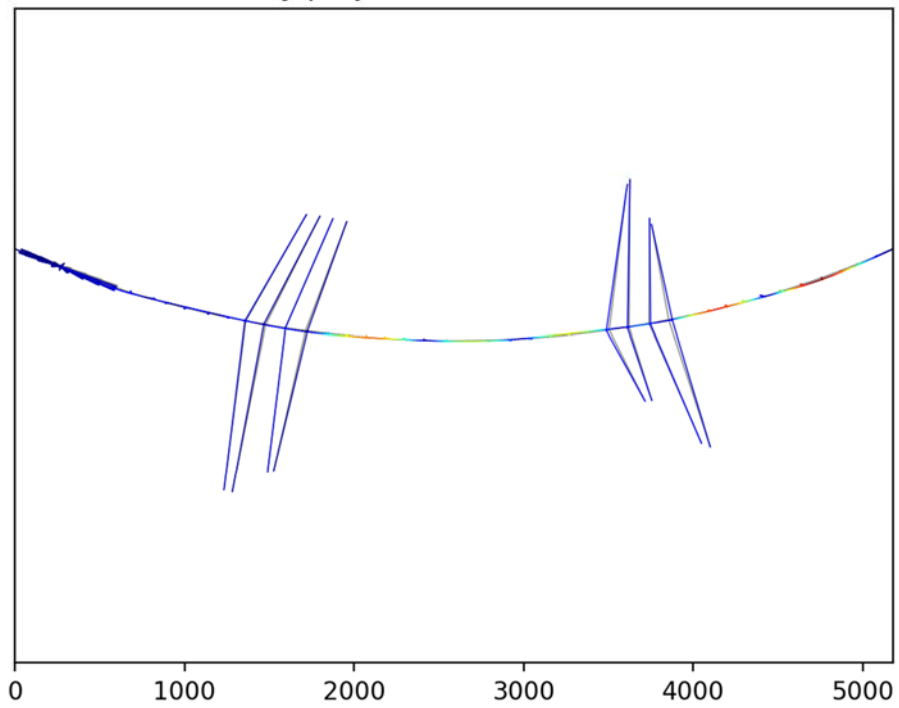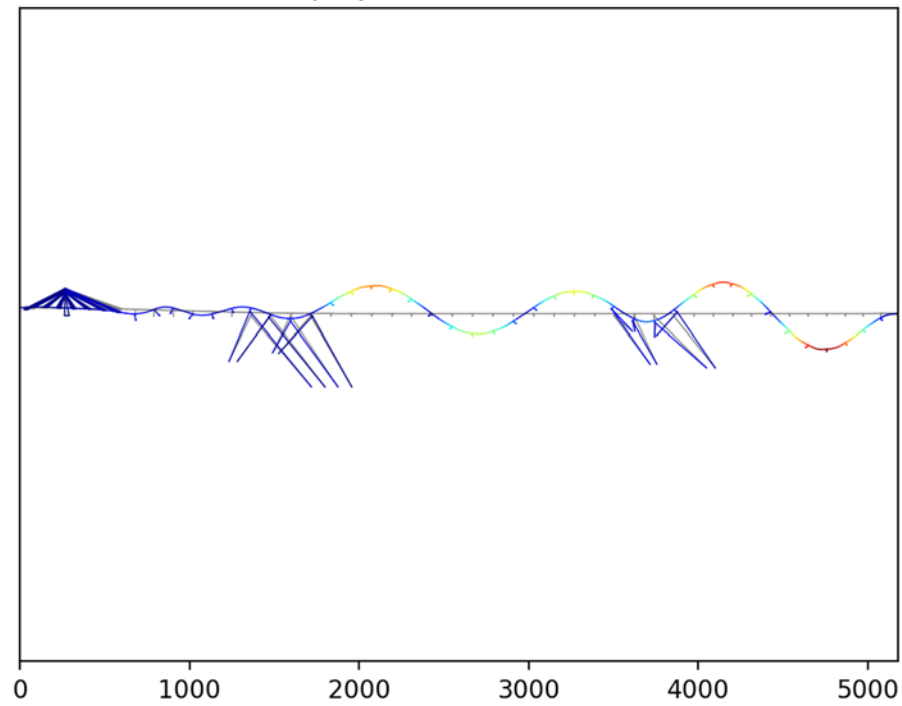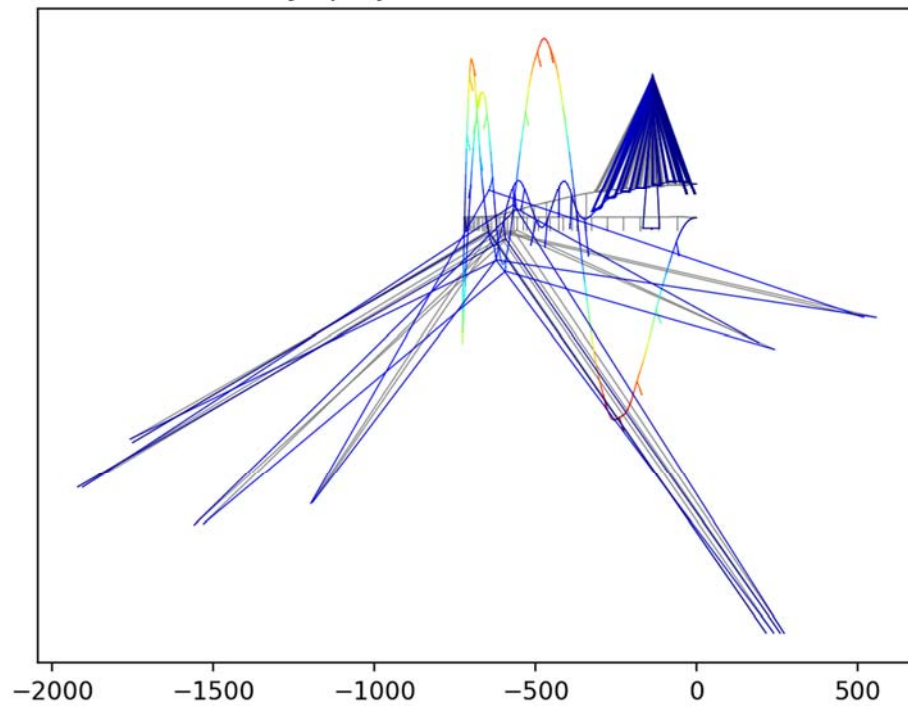iso projection for mode 2
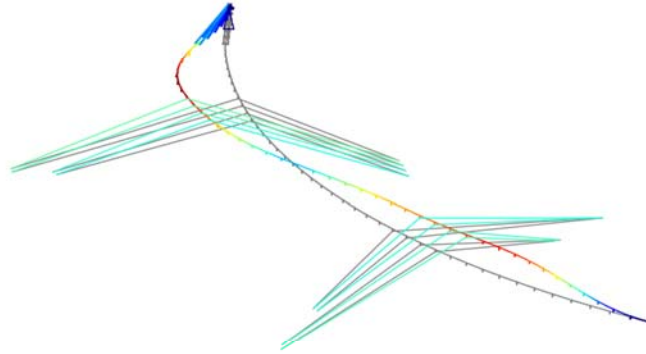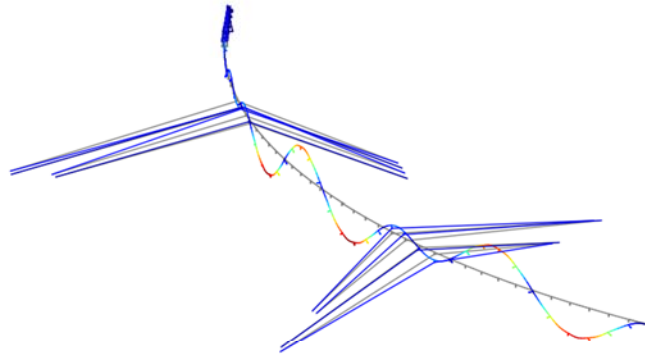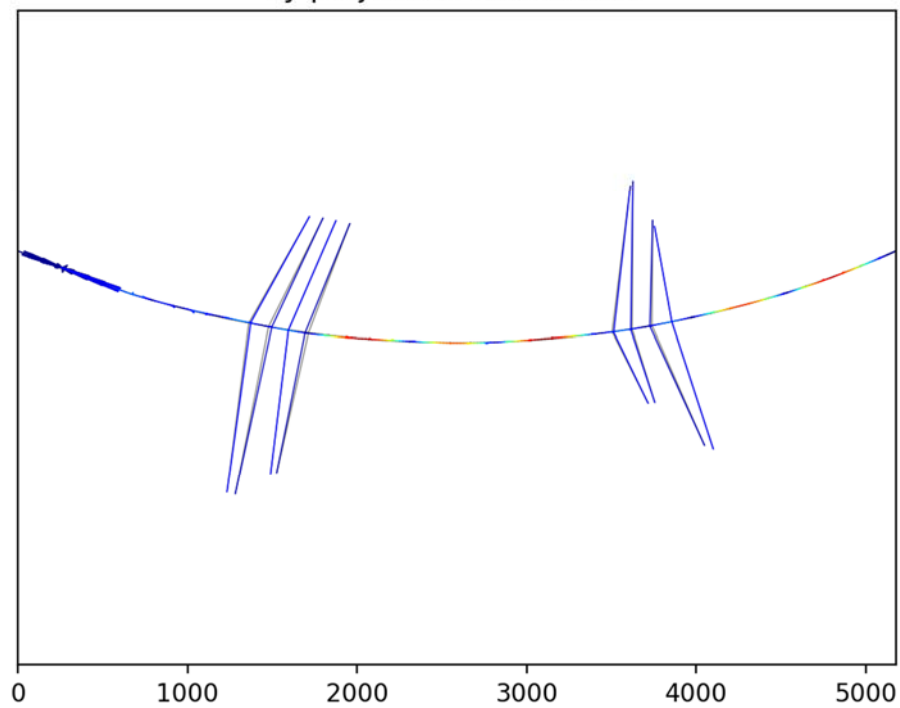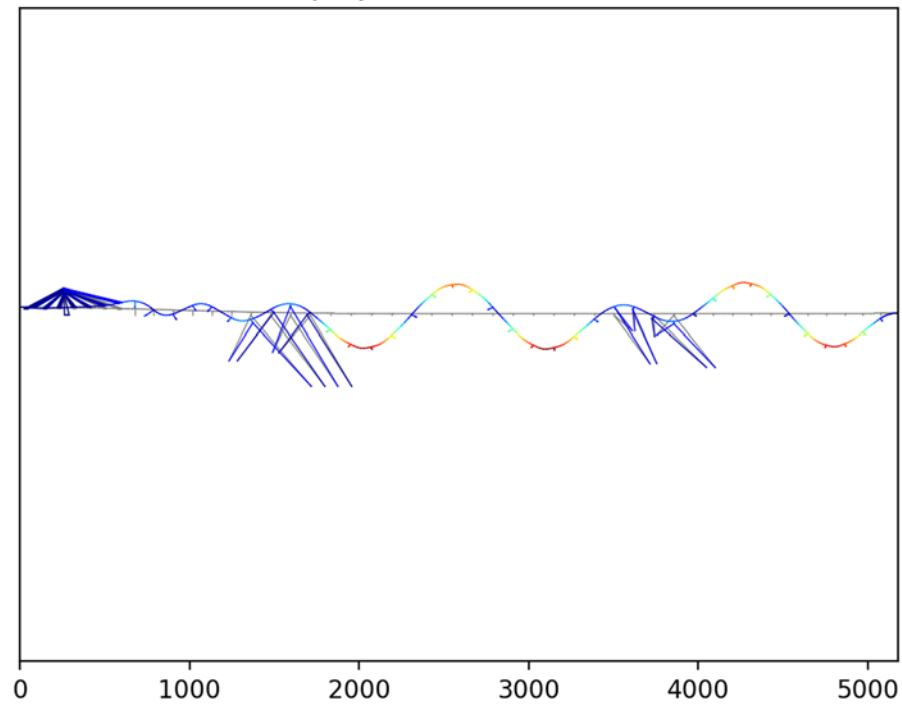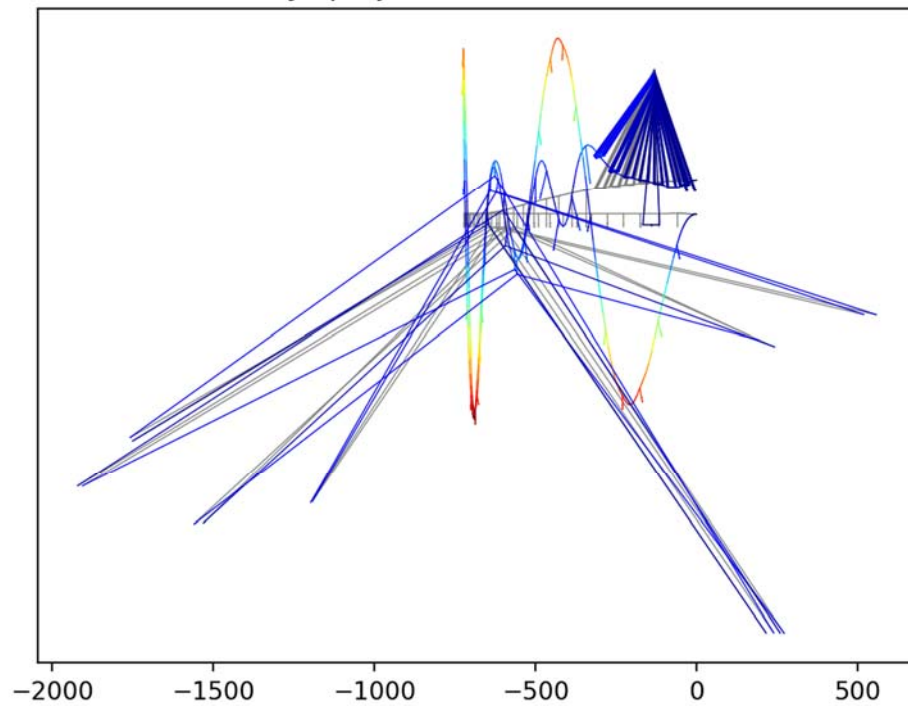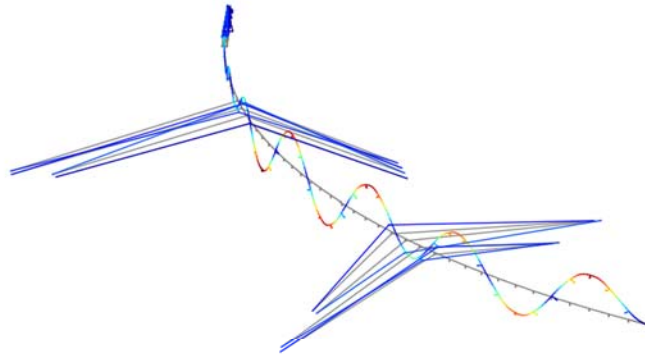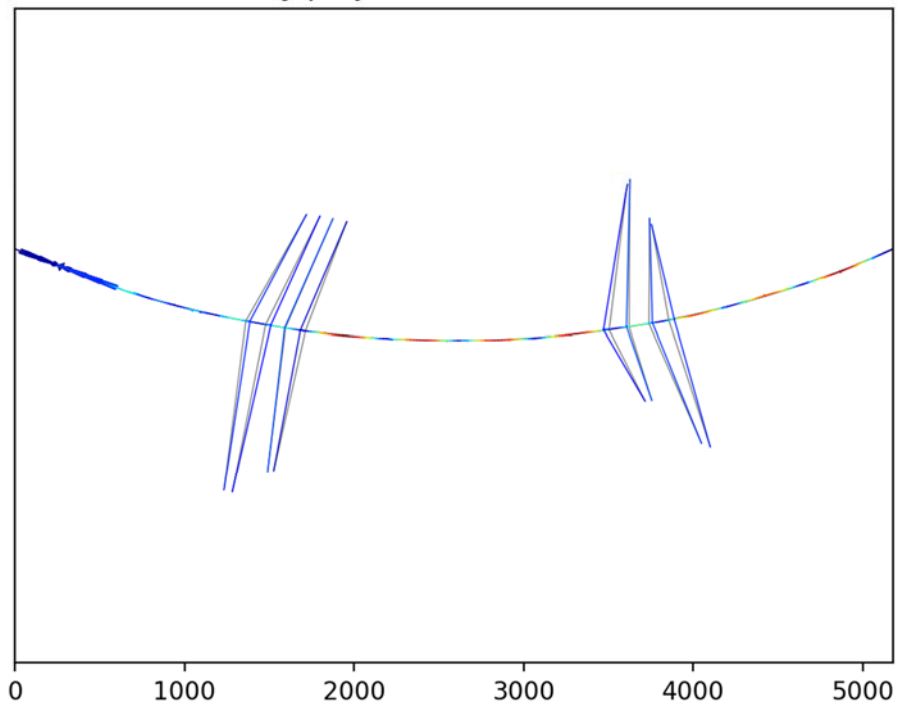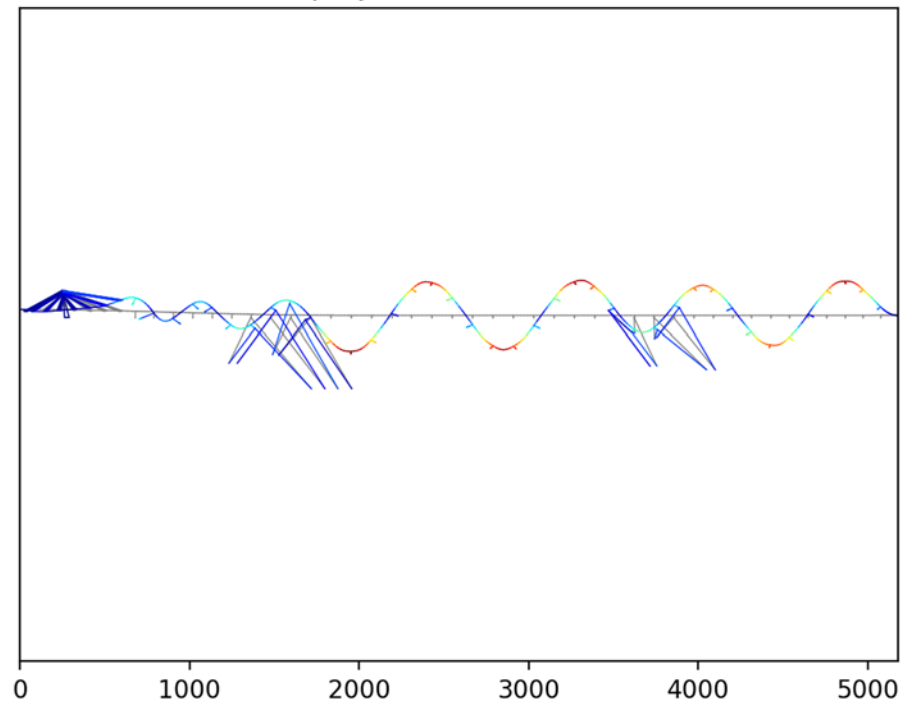

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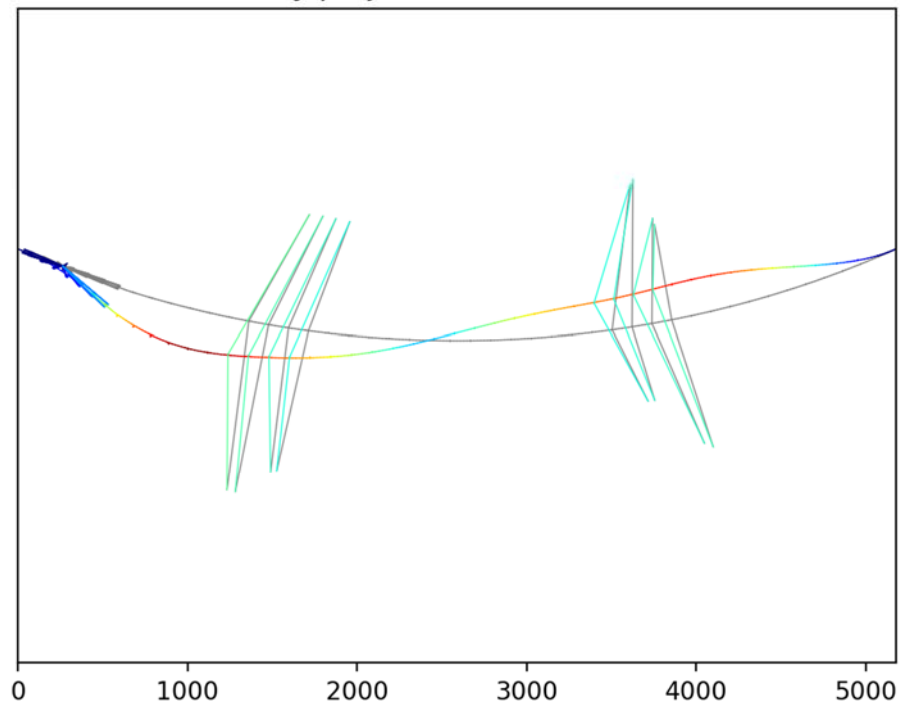
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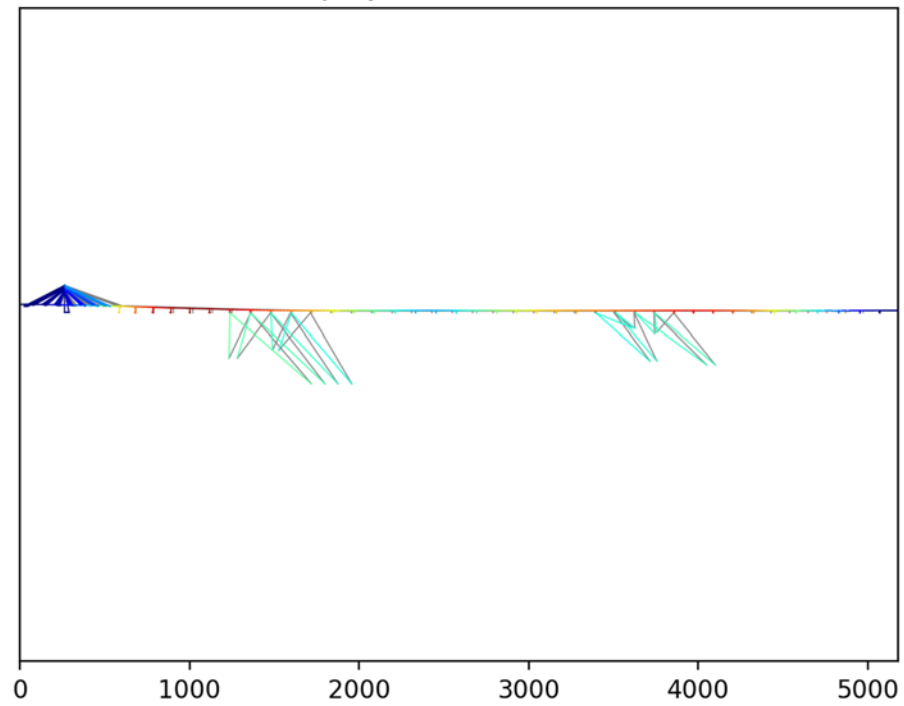
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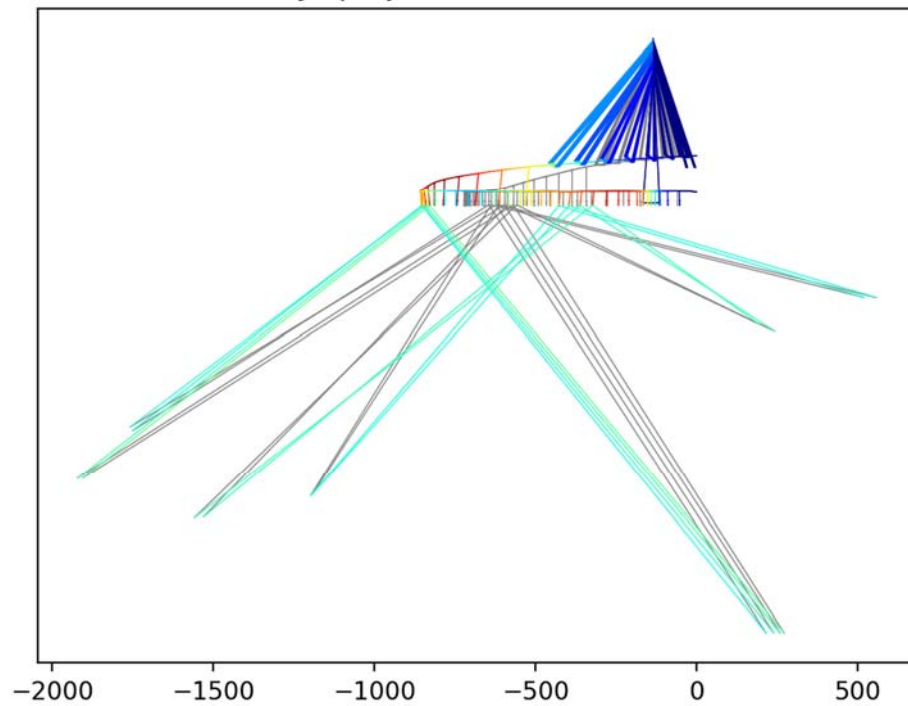
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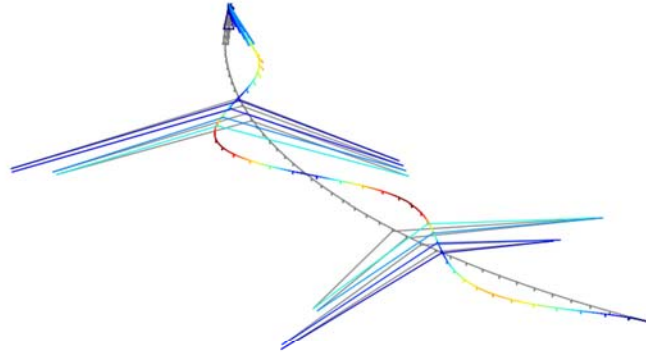
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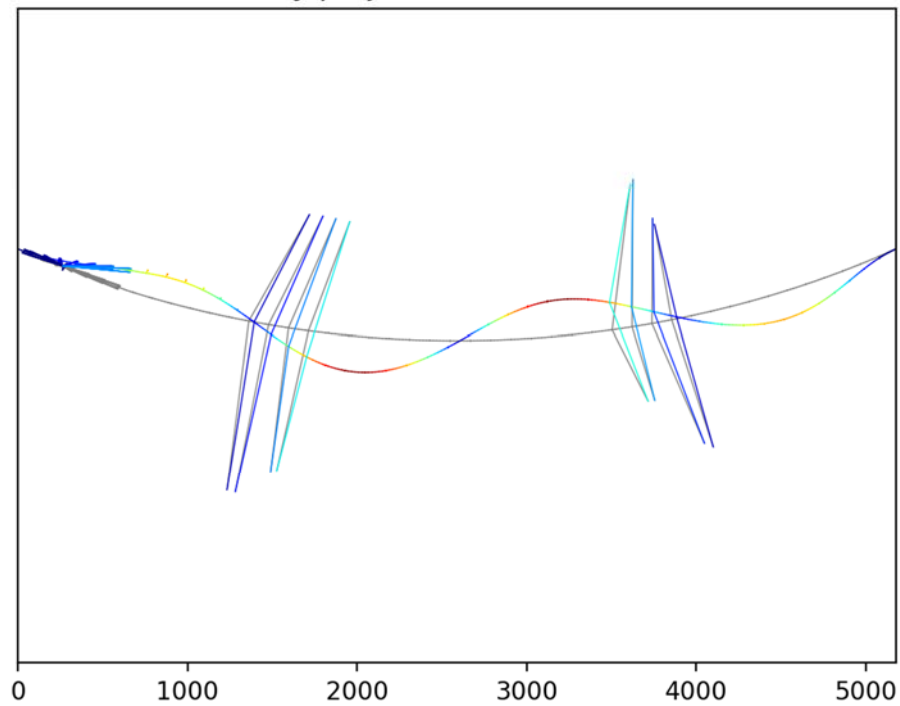
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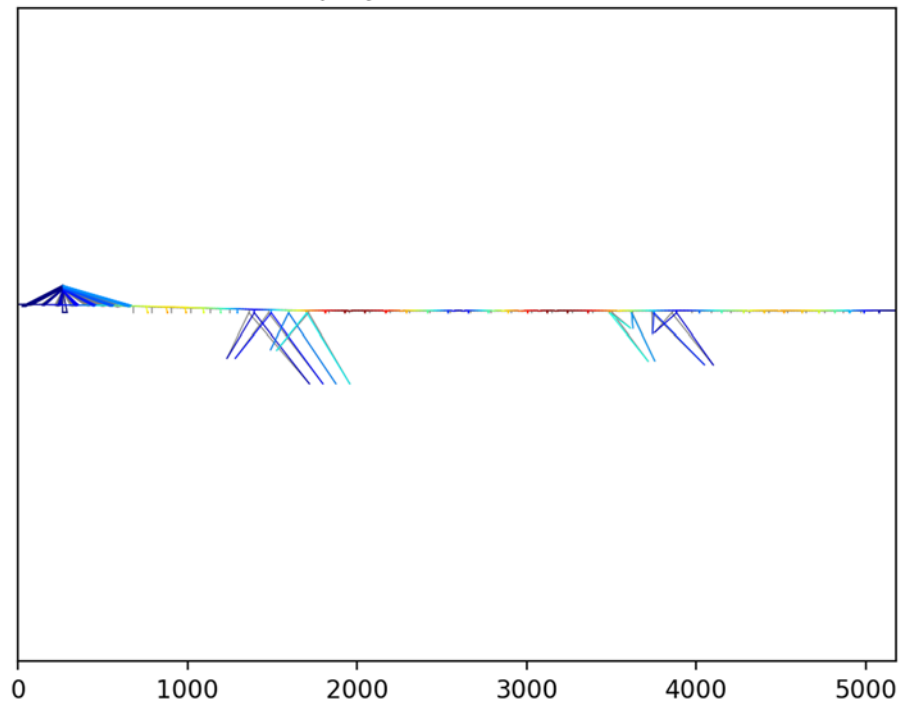
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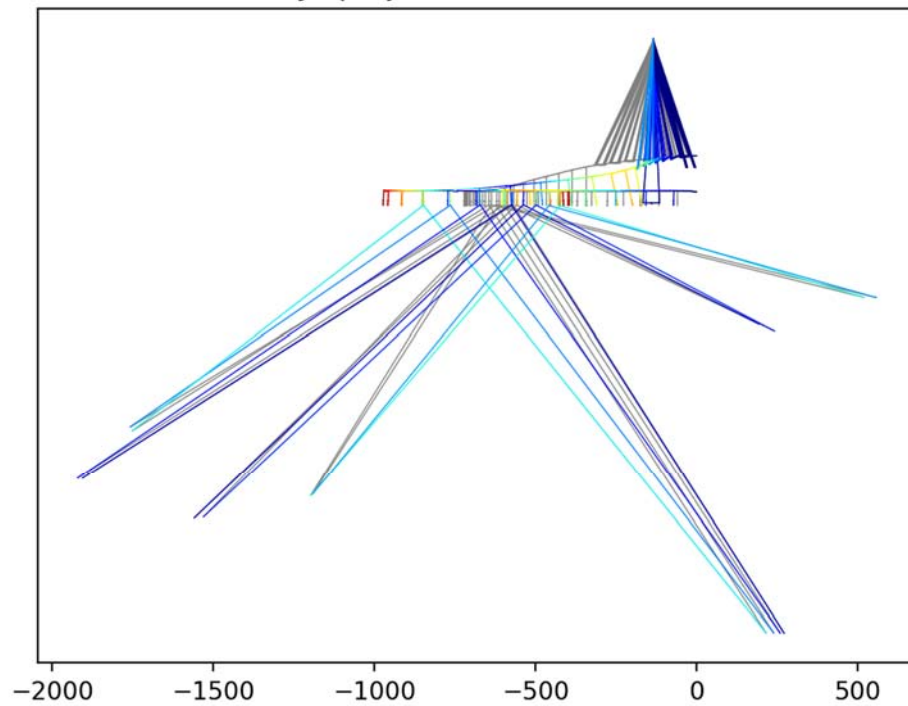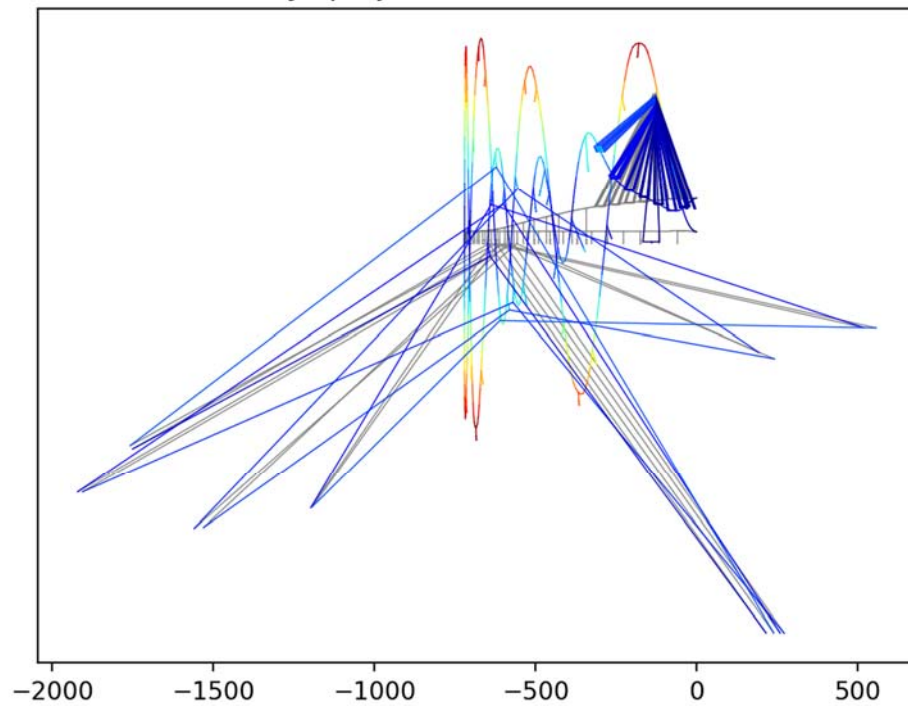
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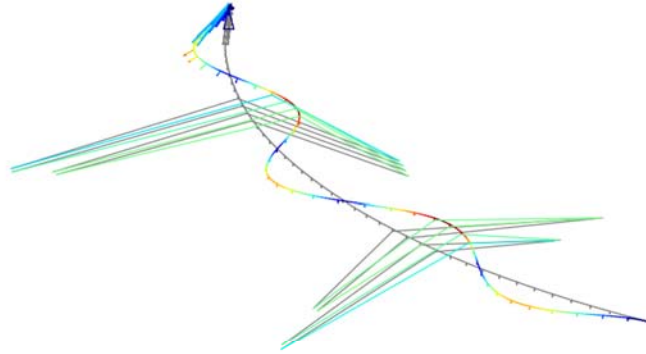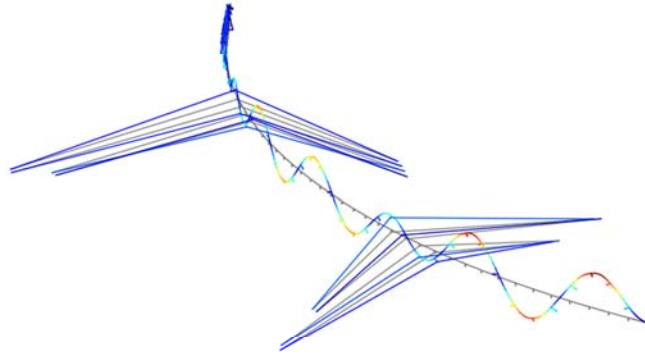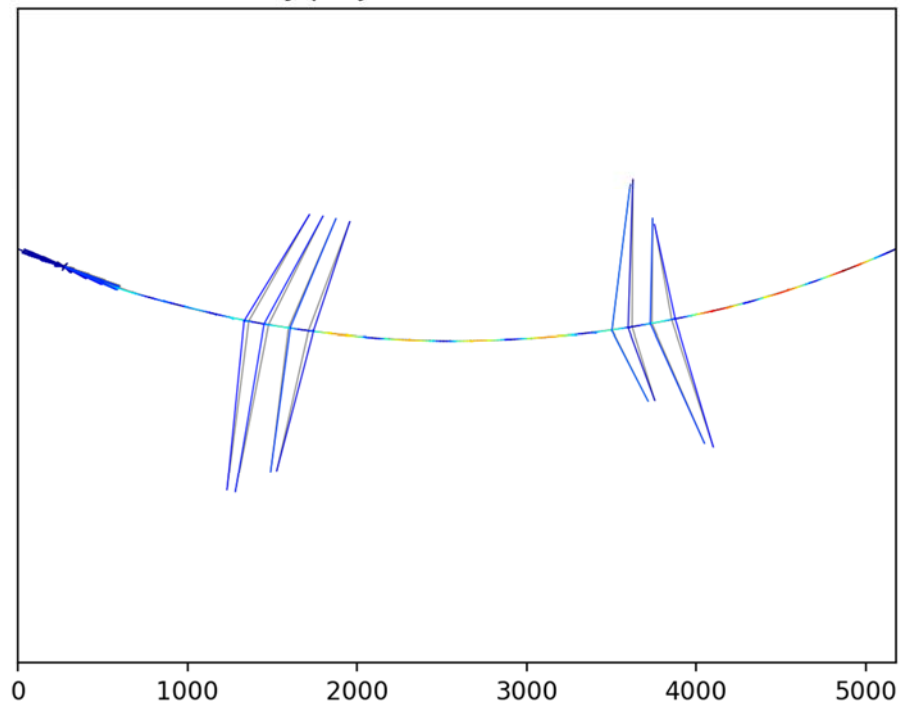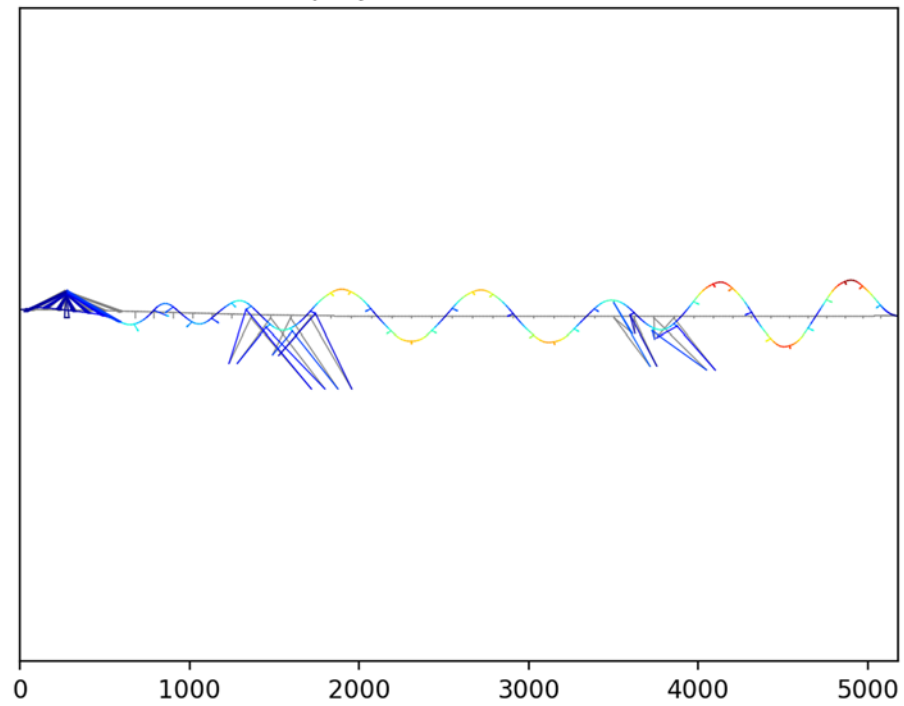

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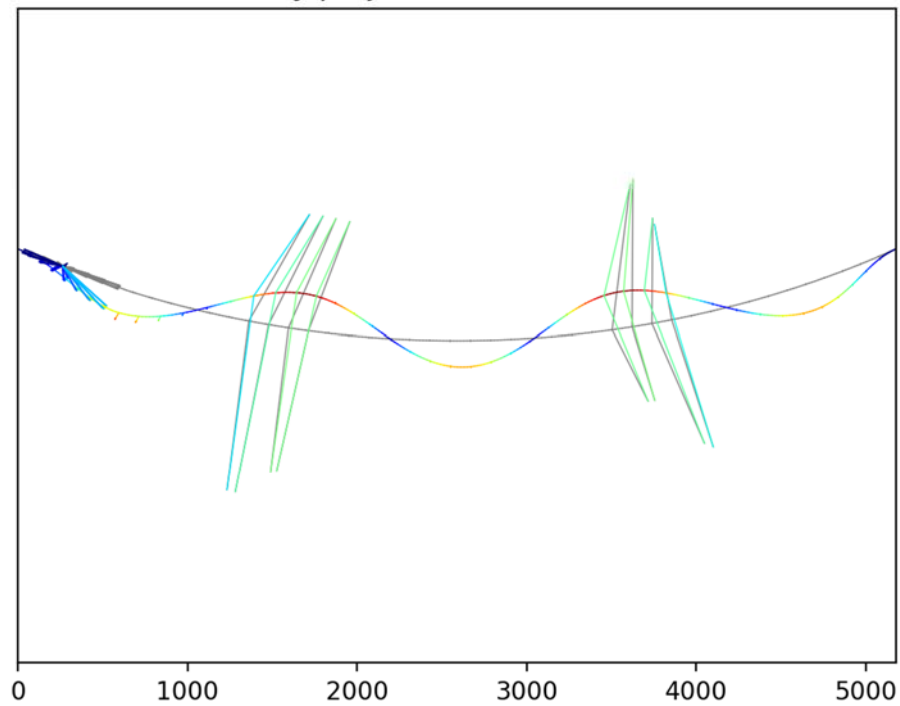
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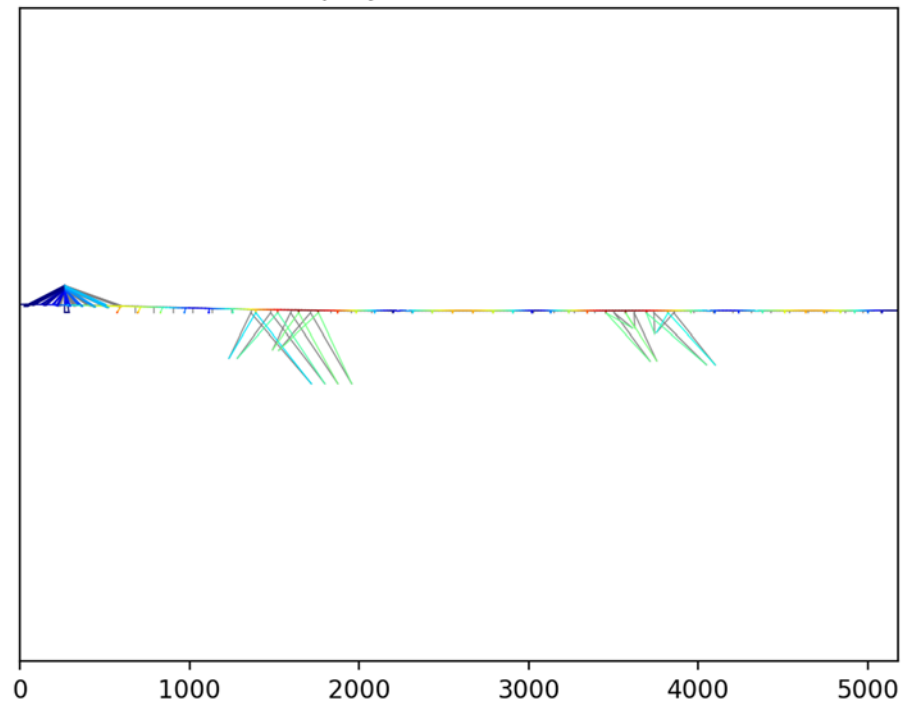
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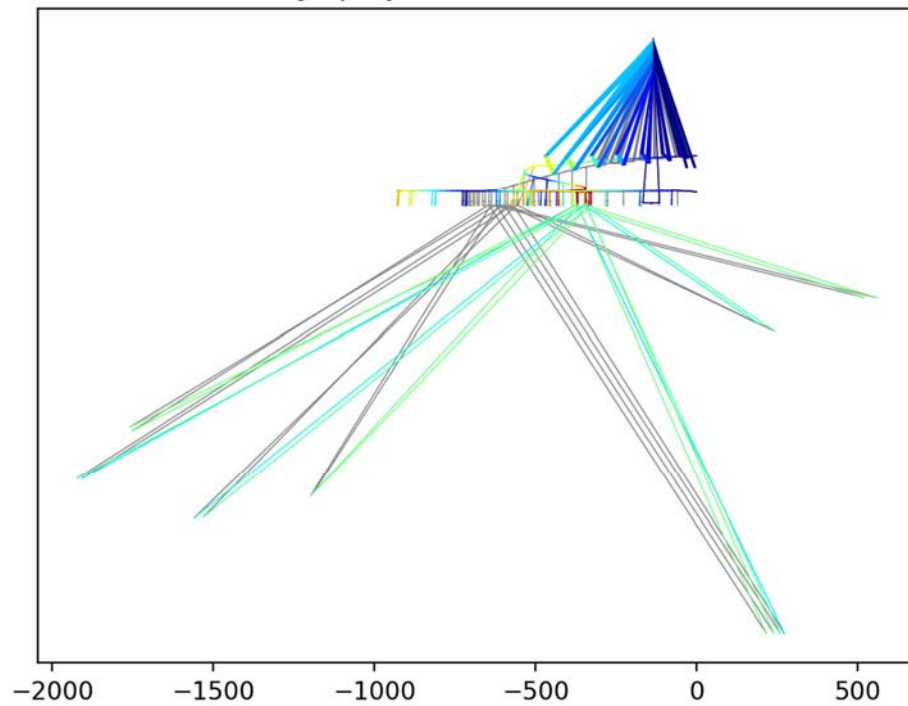
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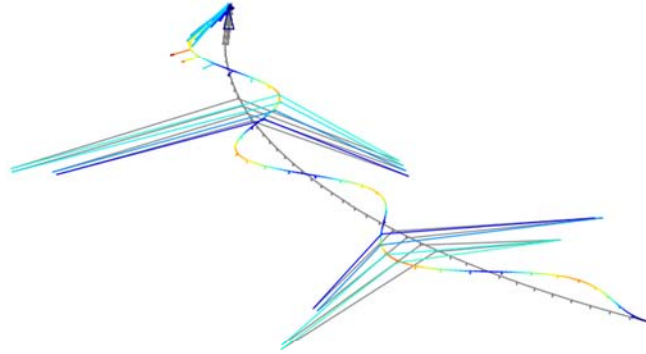
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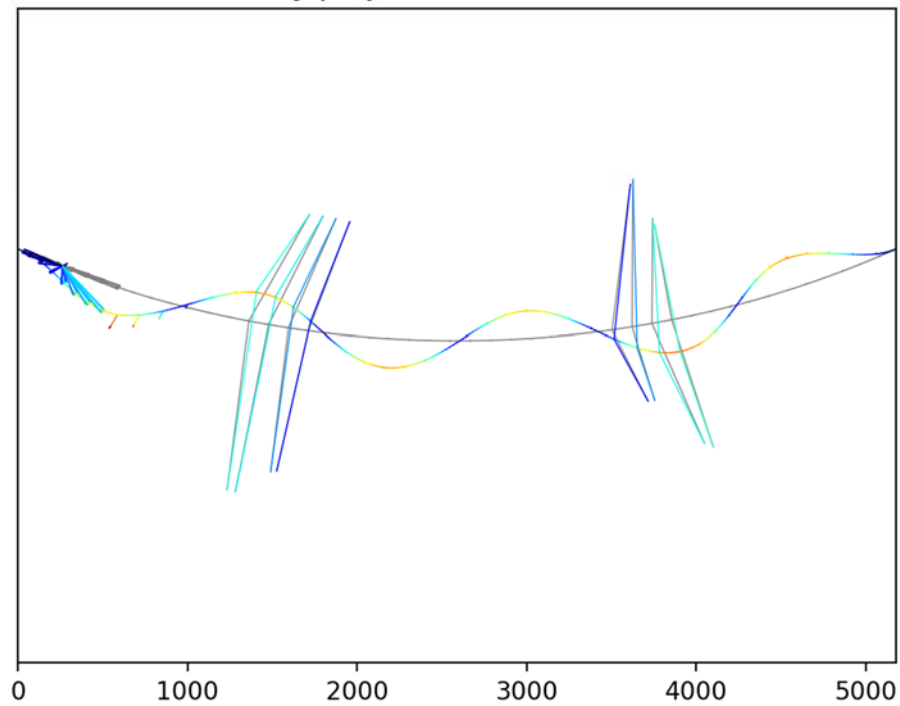
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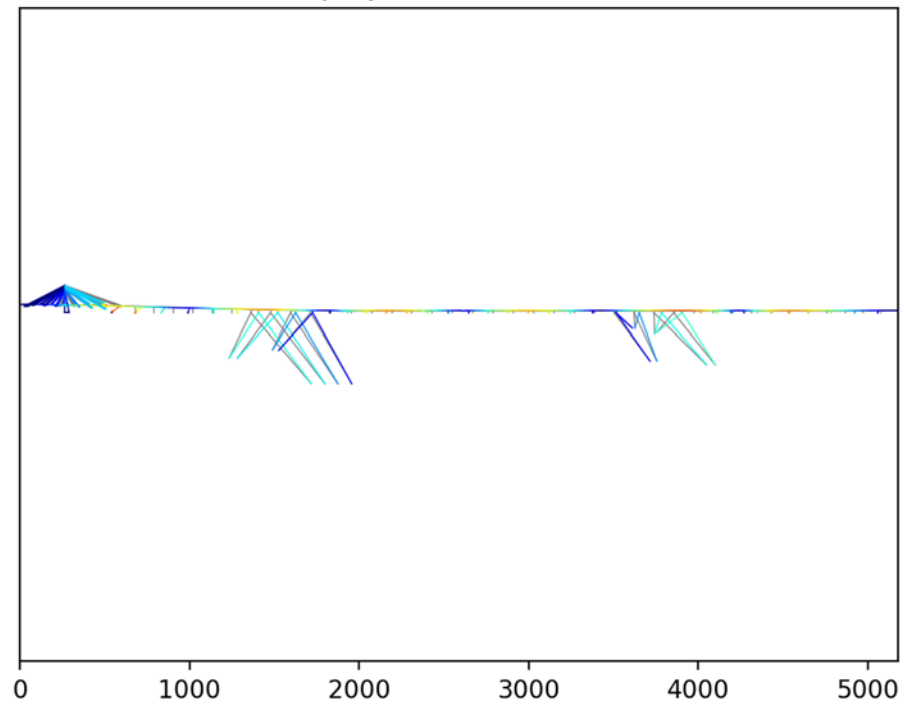
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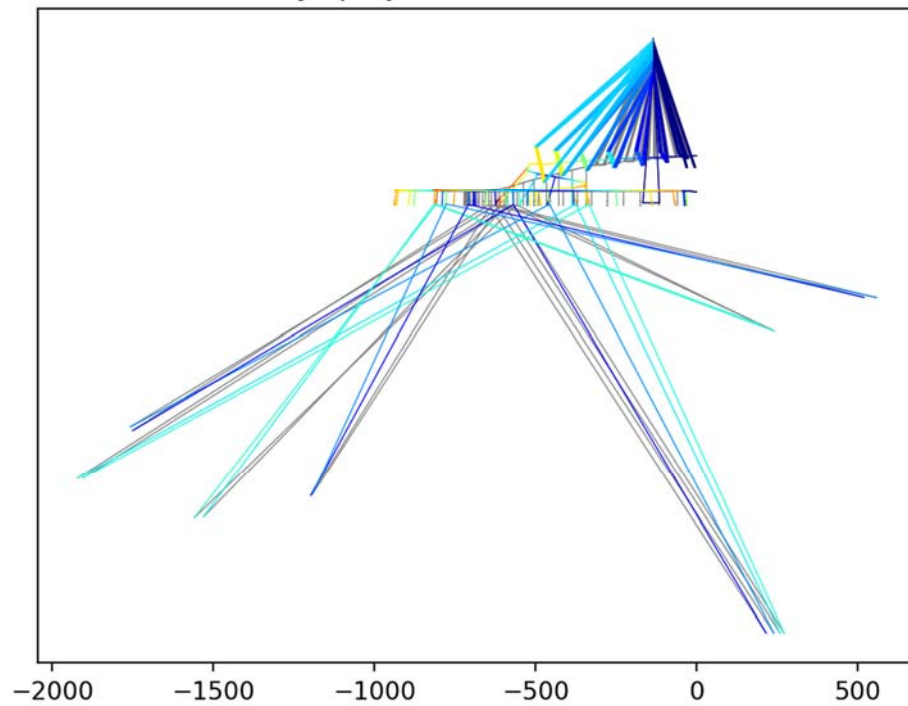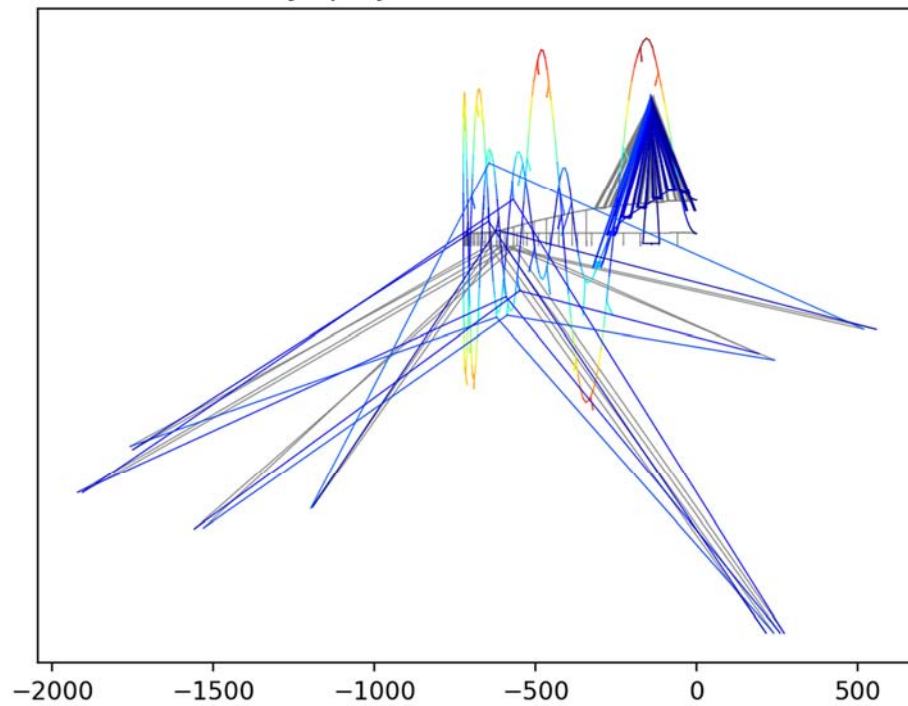
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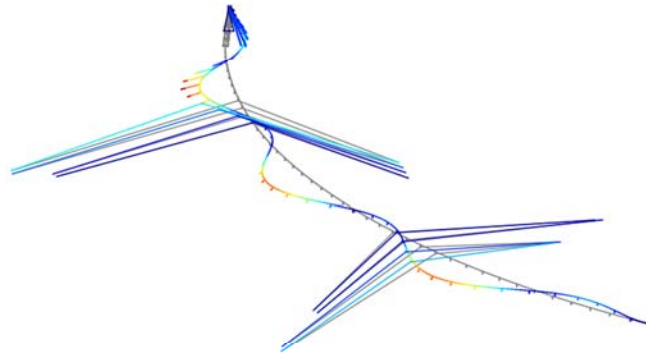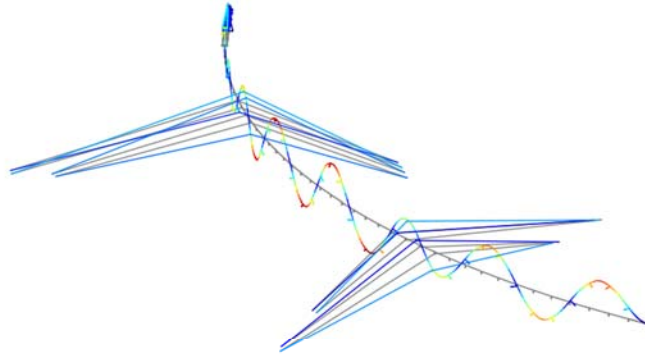

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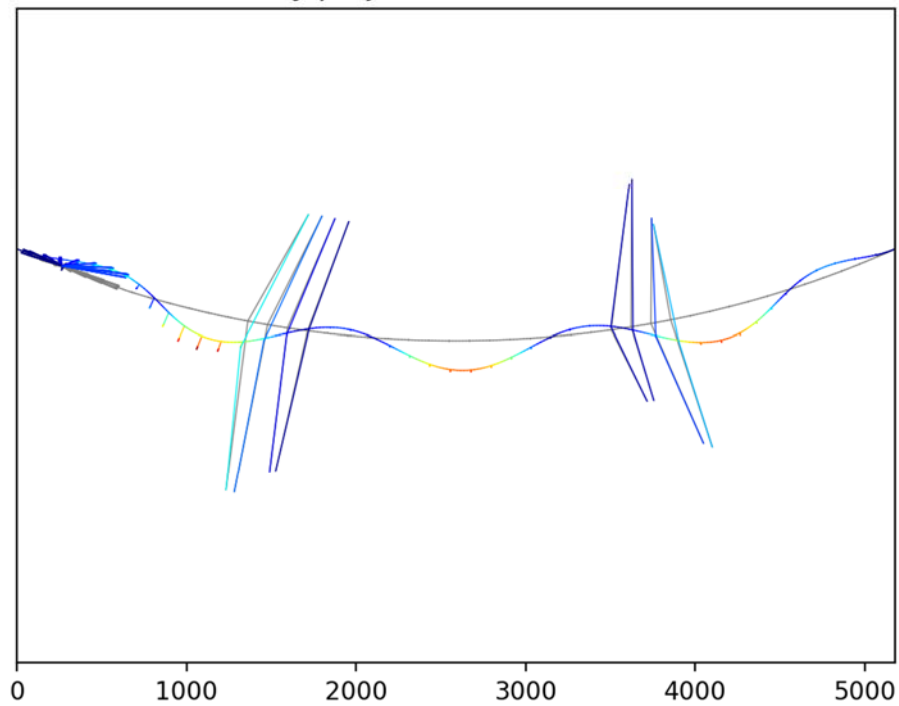
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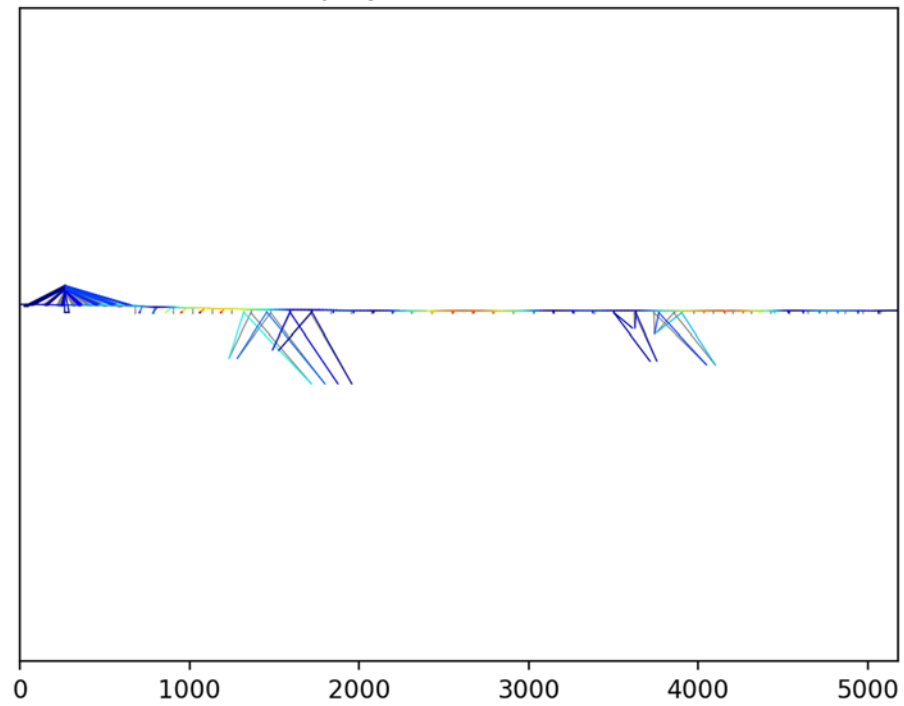
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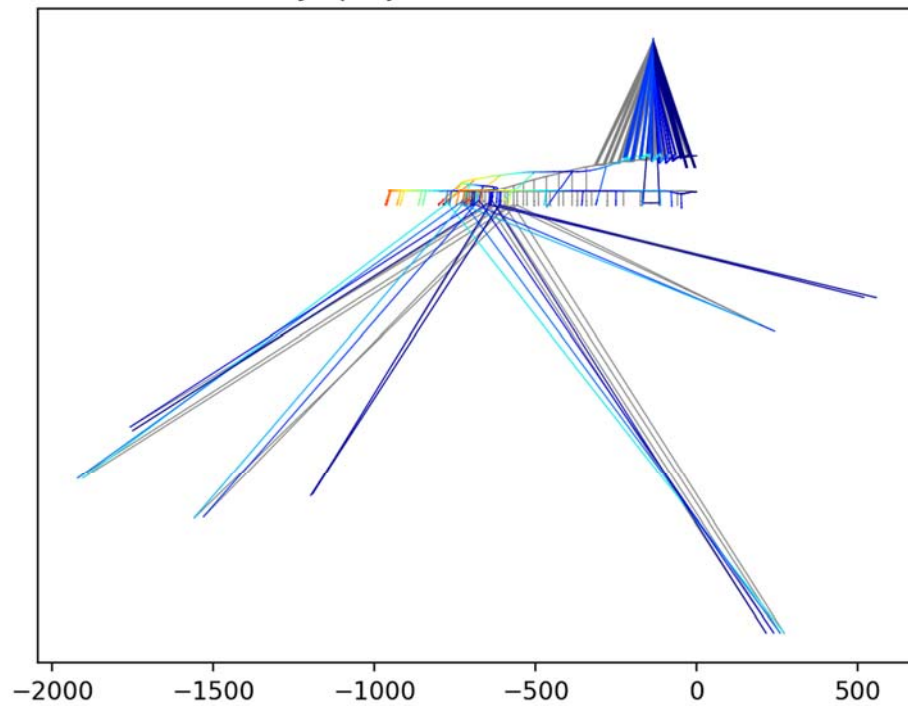
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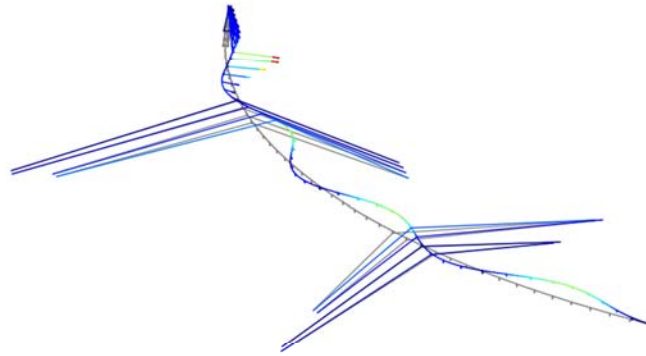
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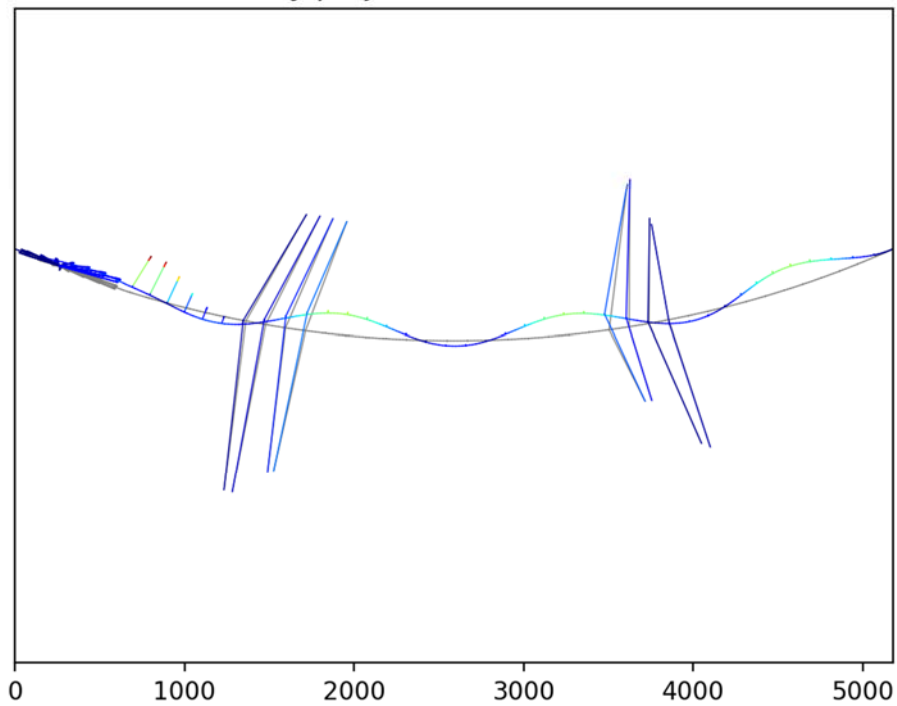
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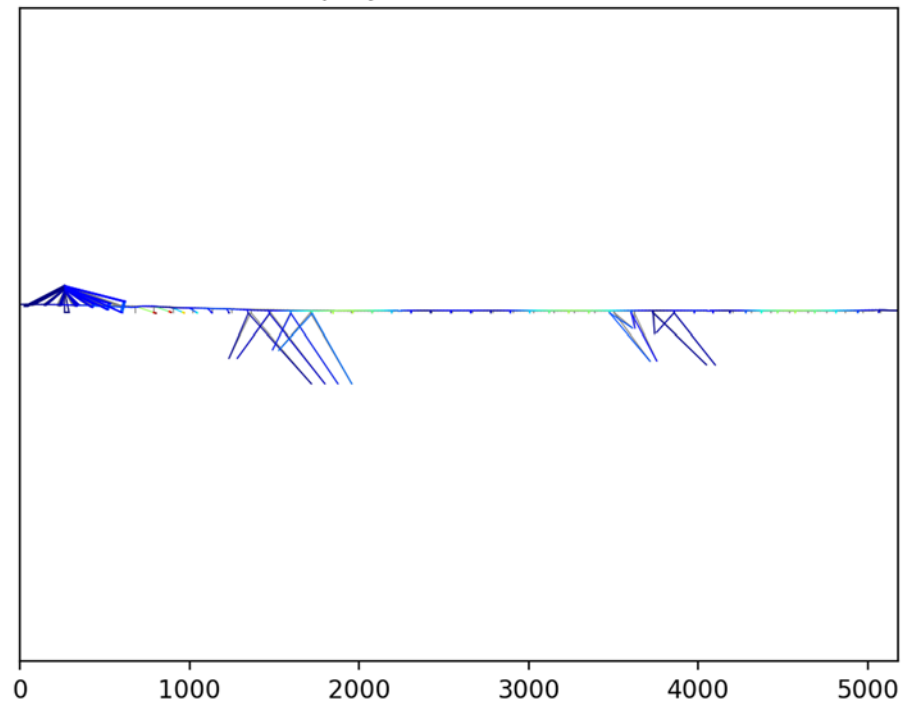
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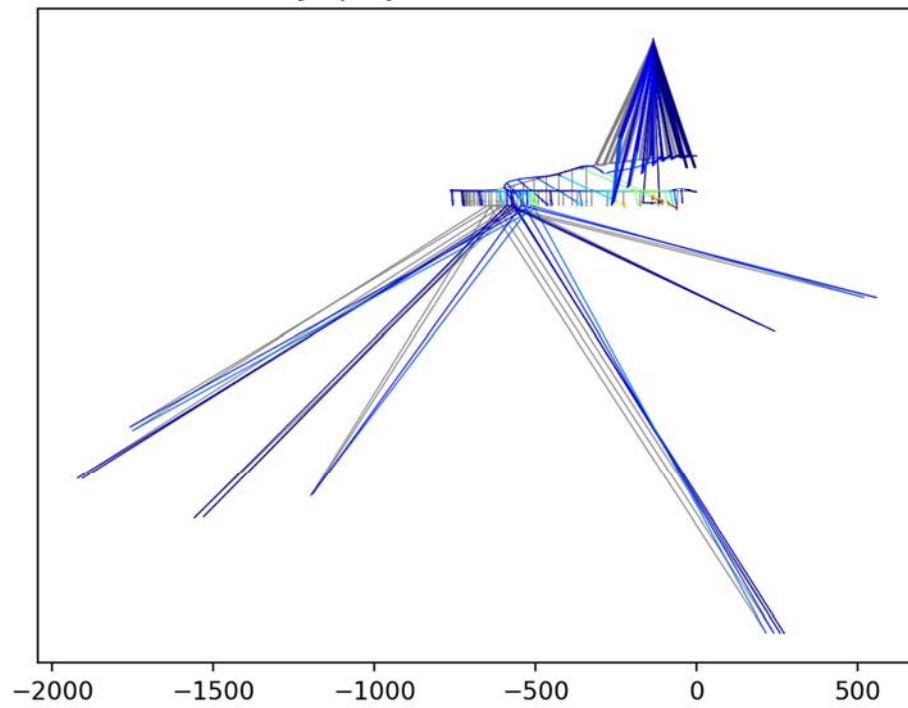
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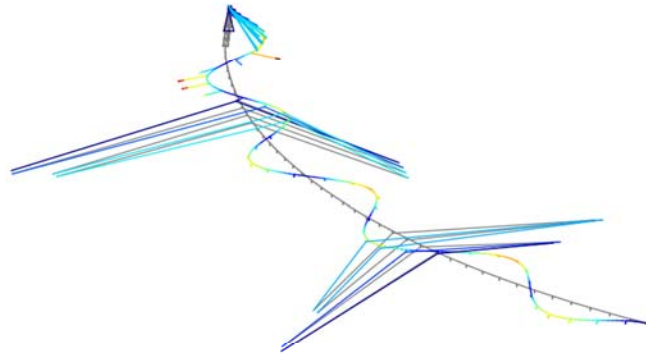
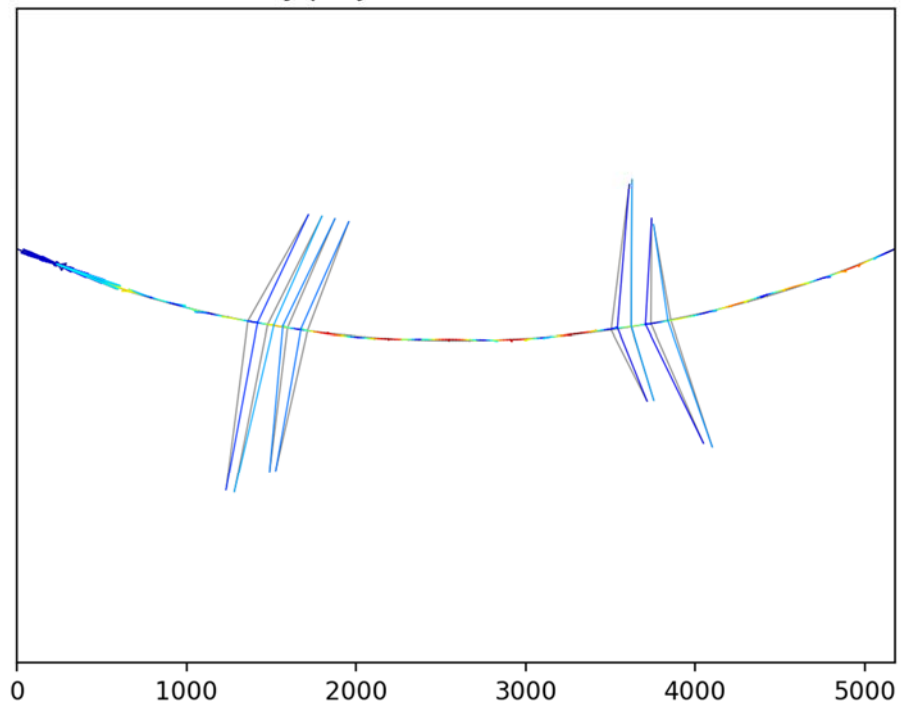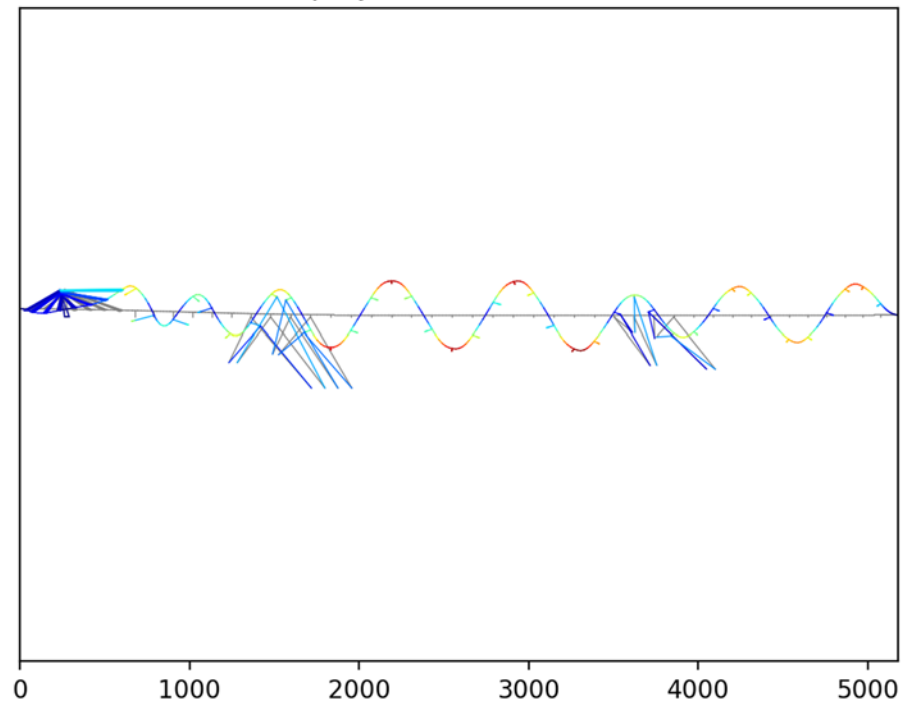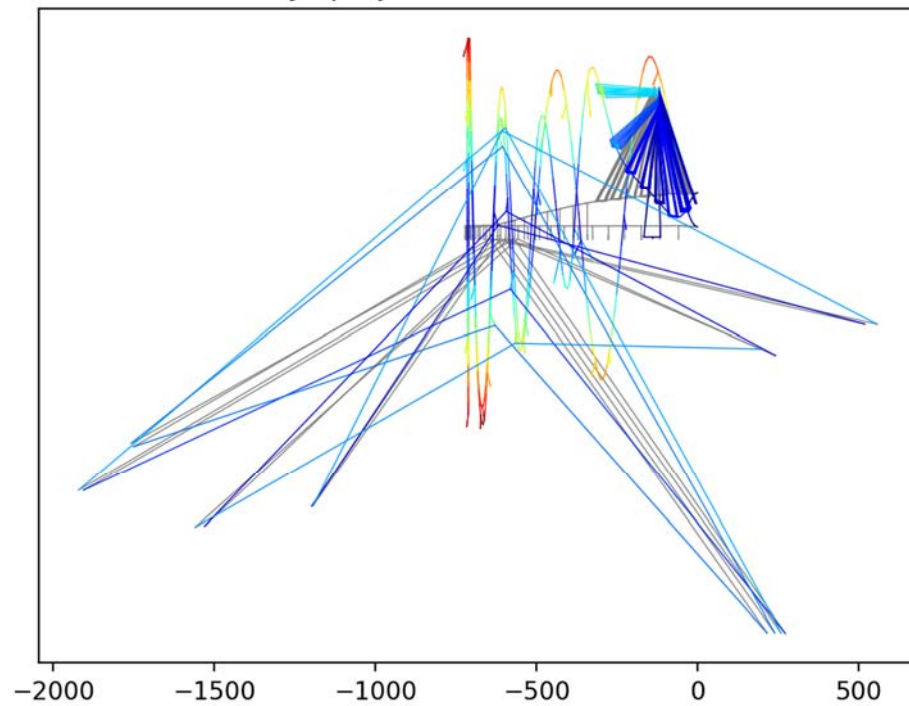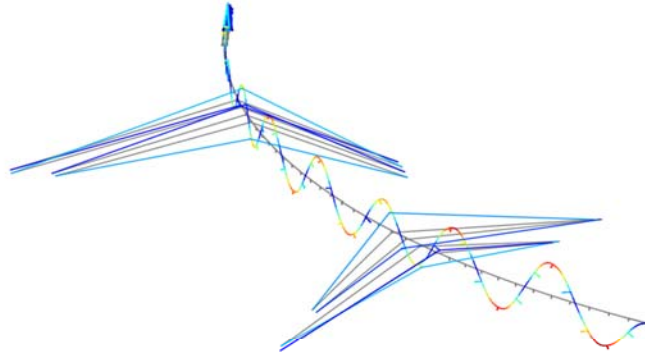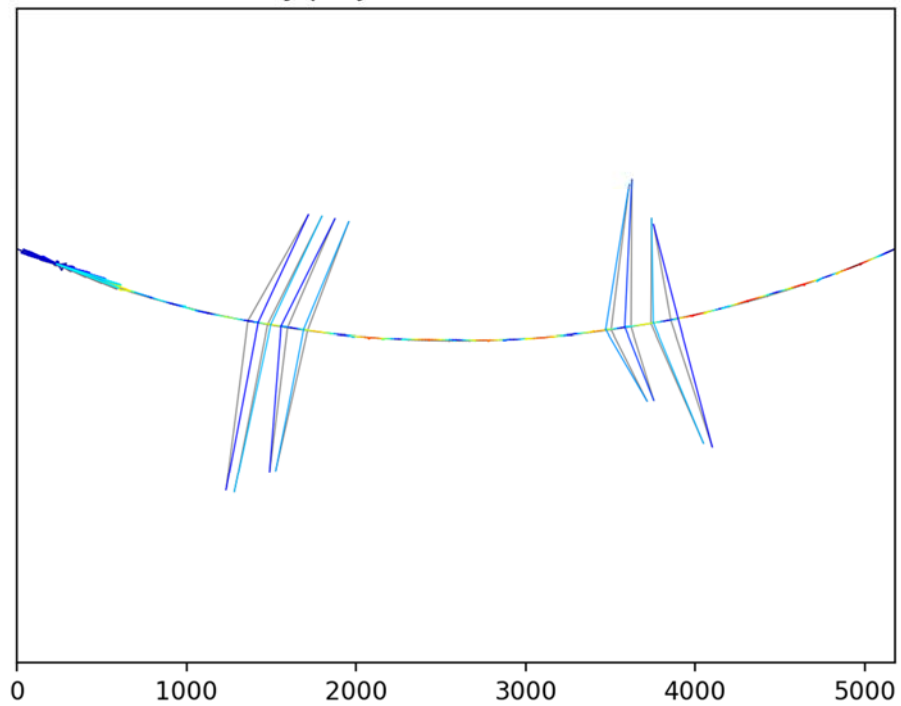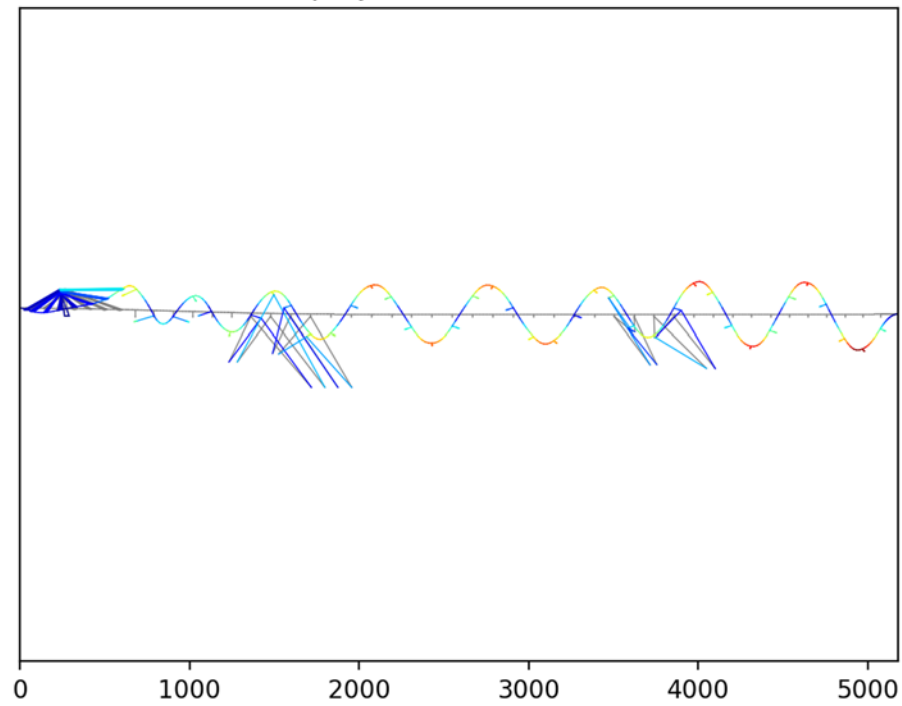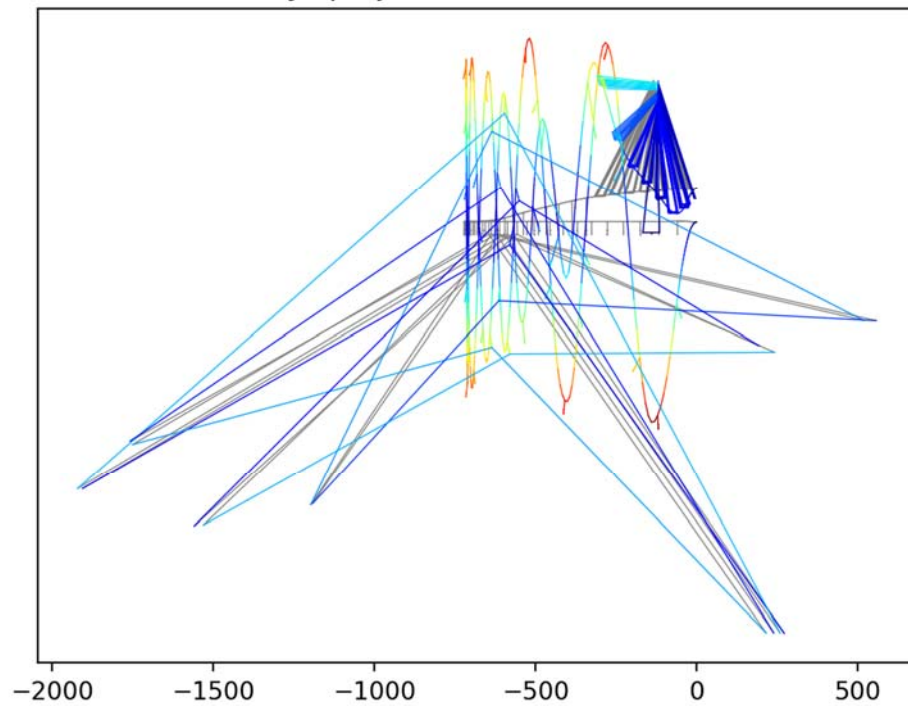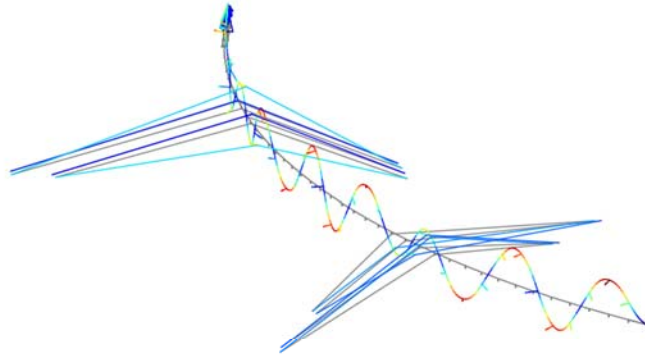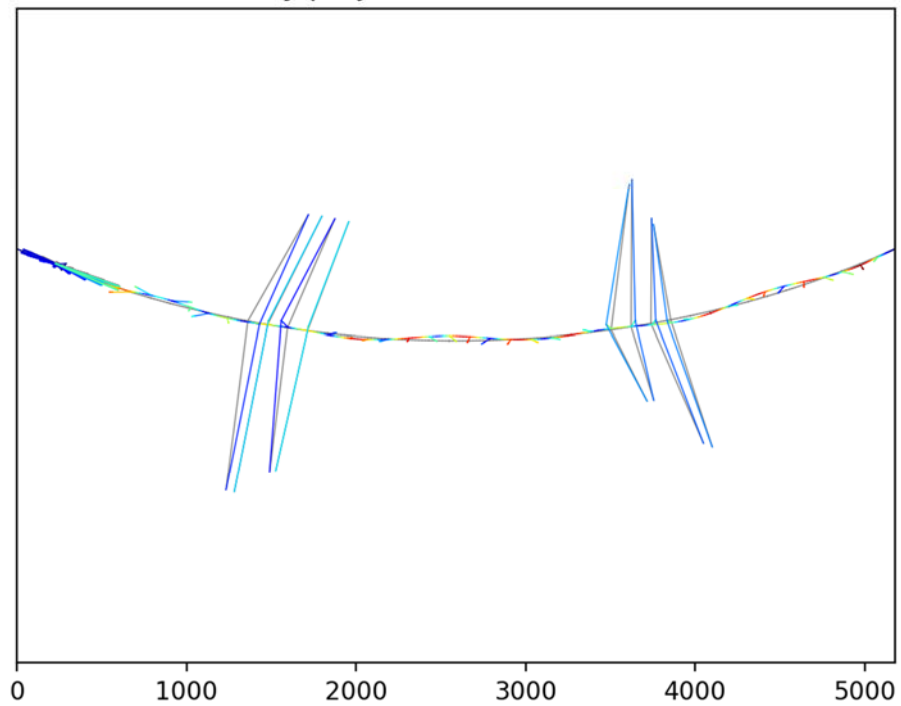xy projection for mode 8
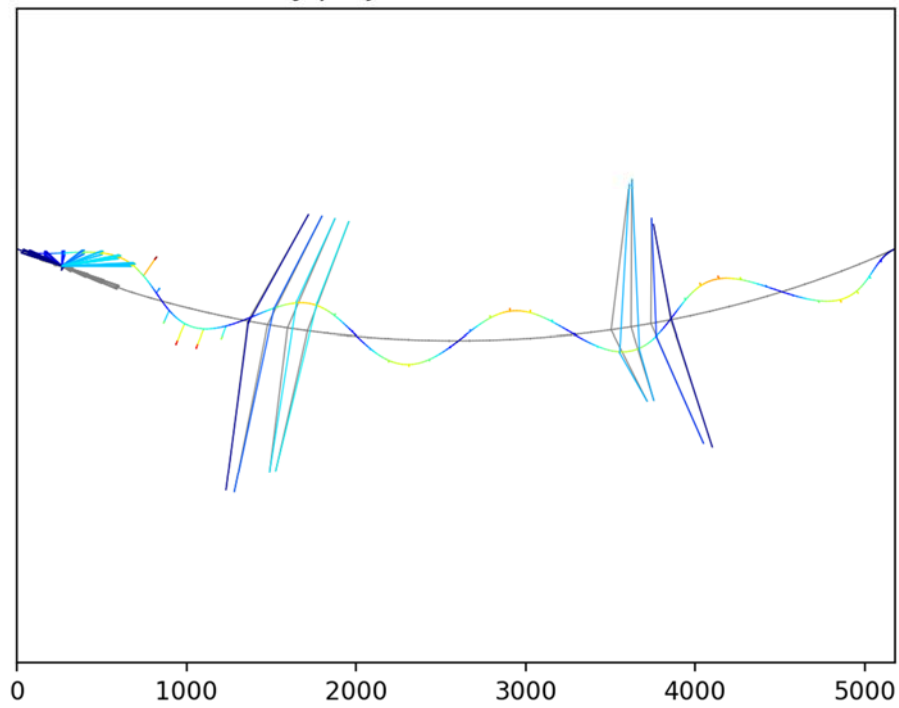
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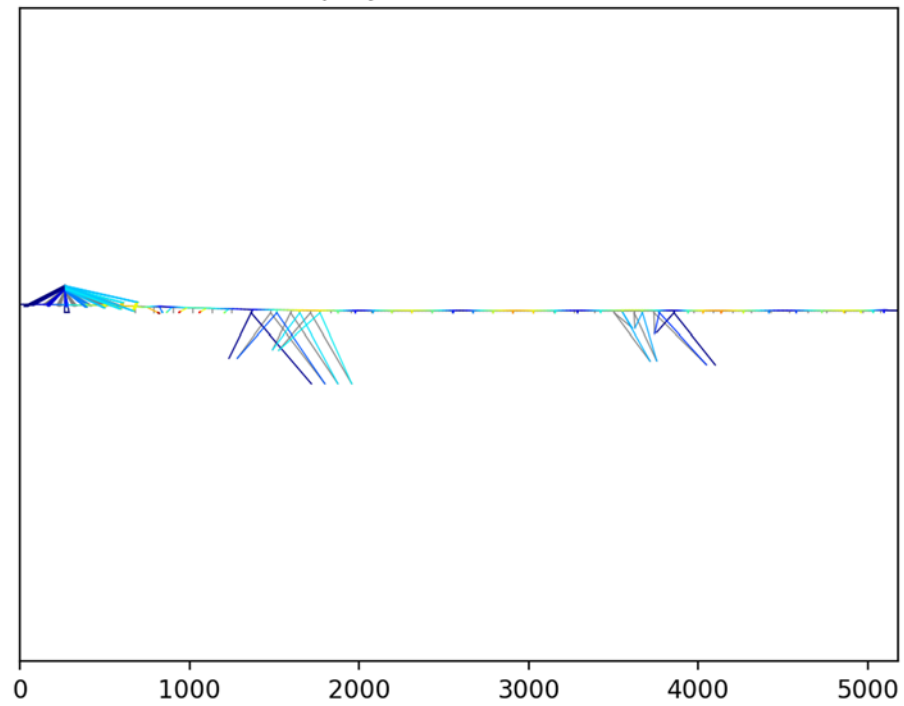
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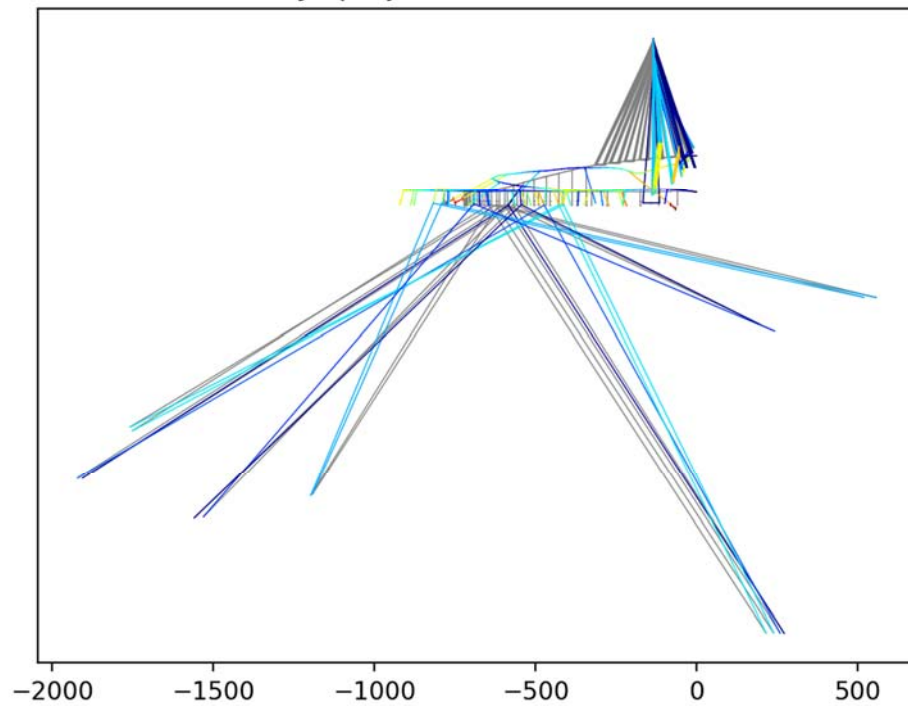
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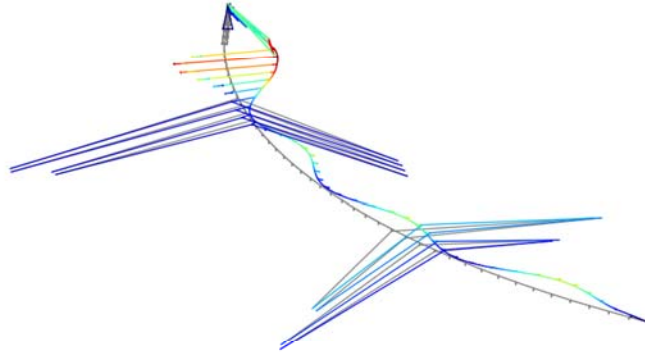
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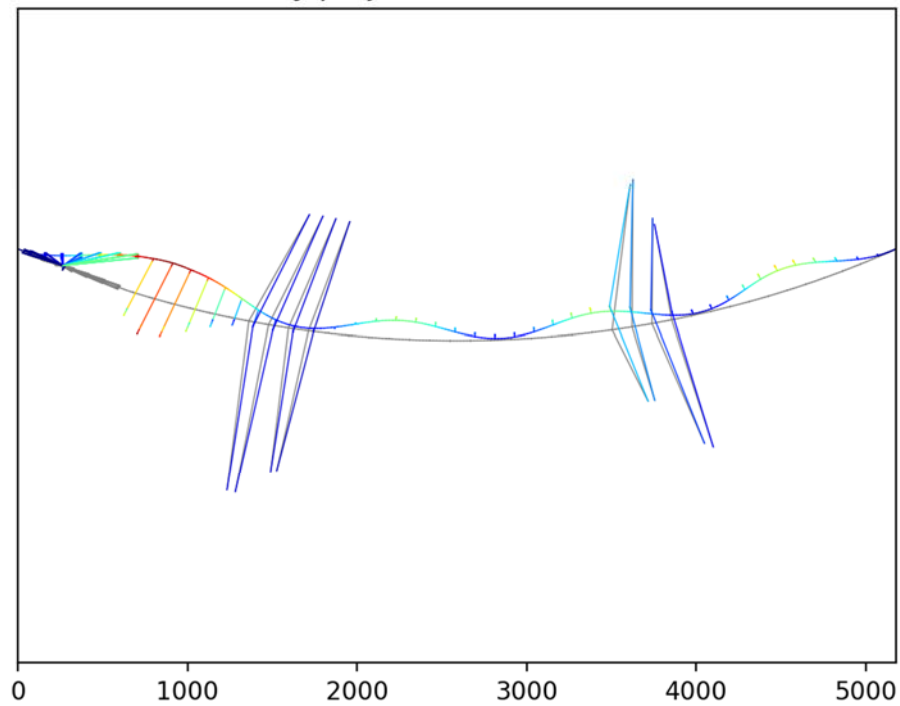
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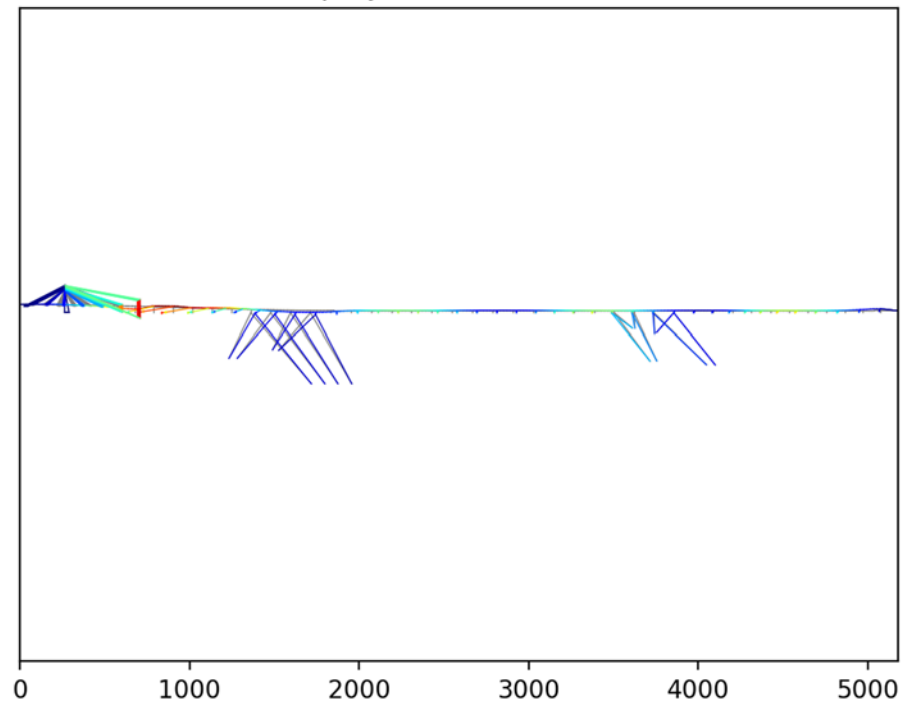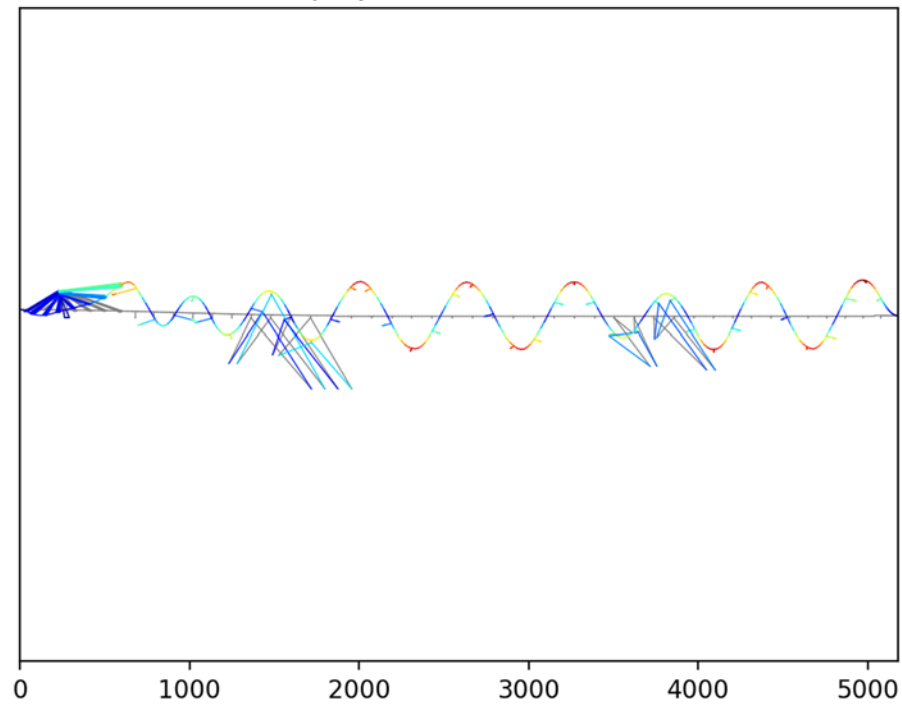

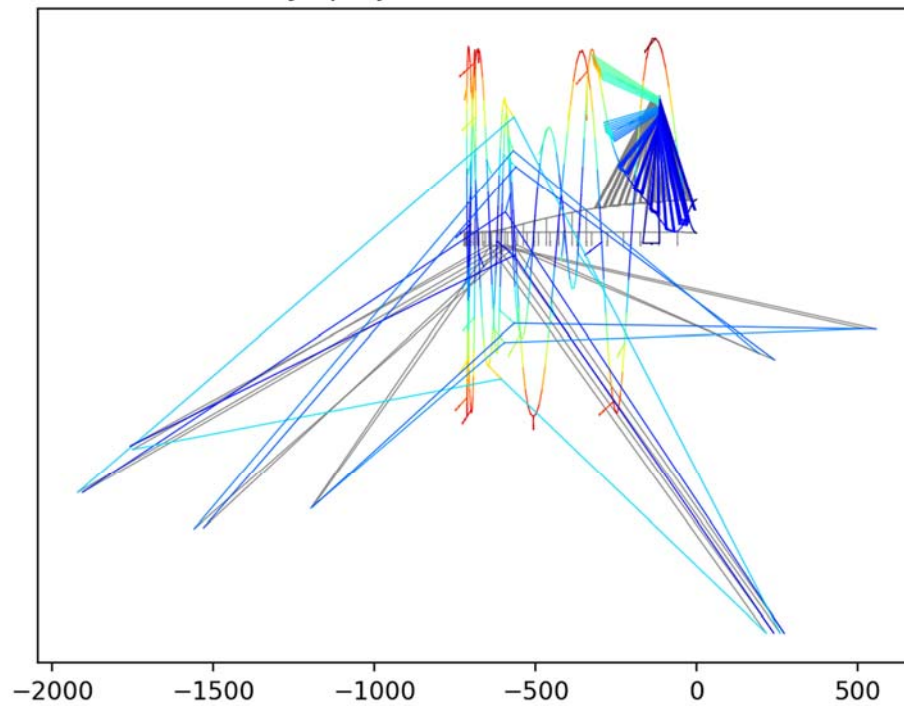## yz projection for mode 9
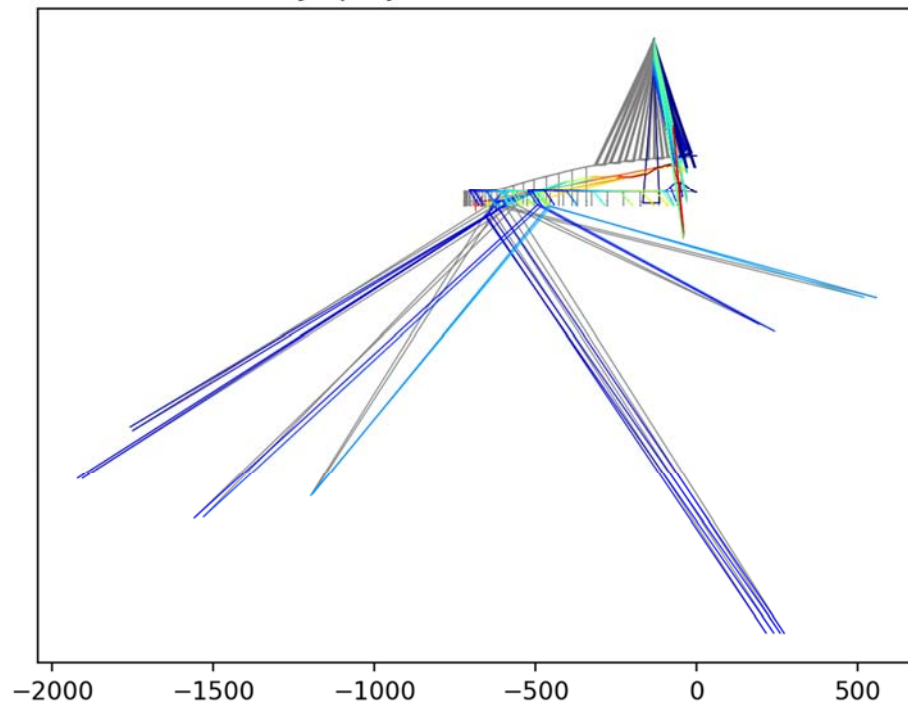
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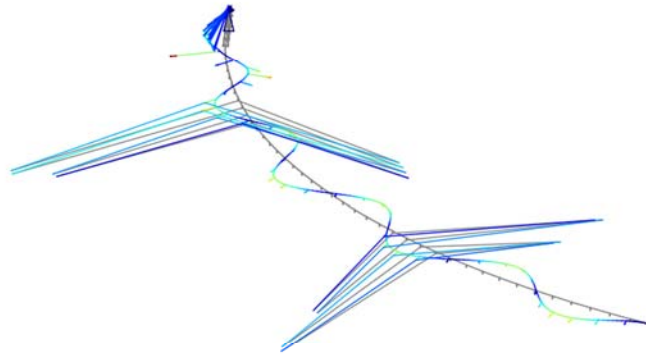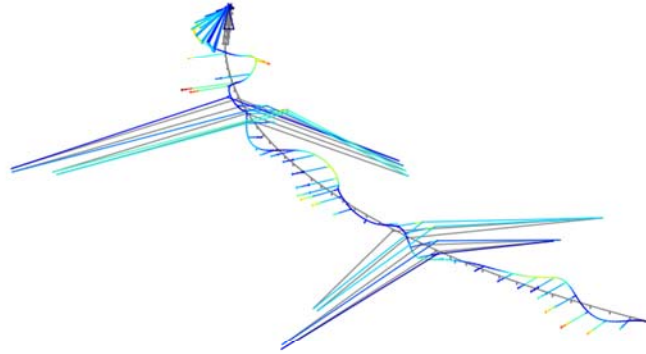

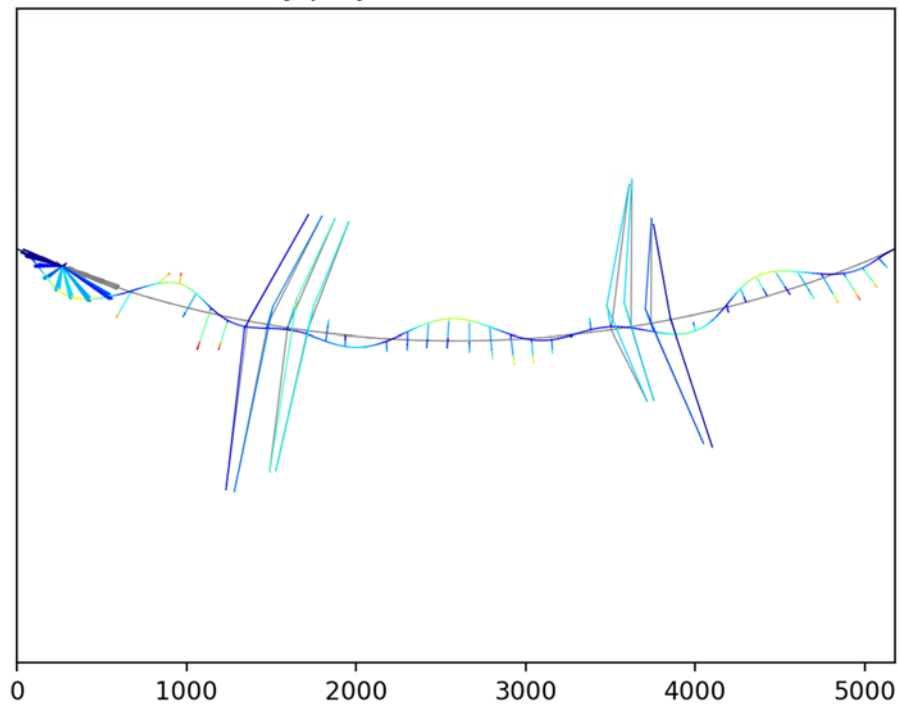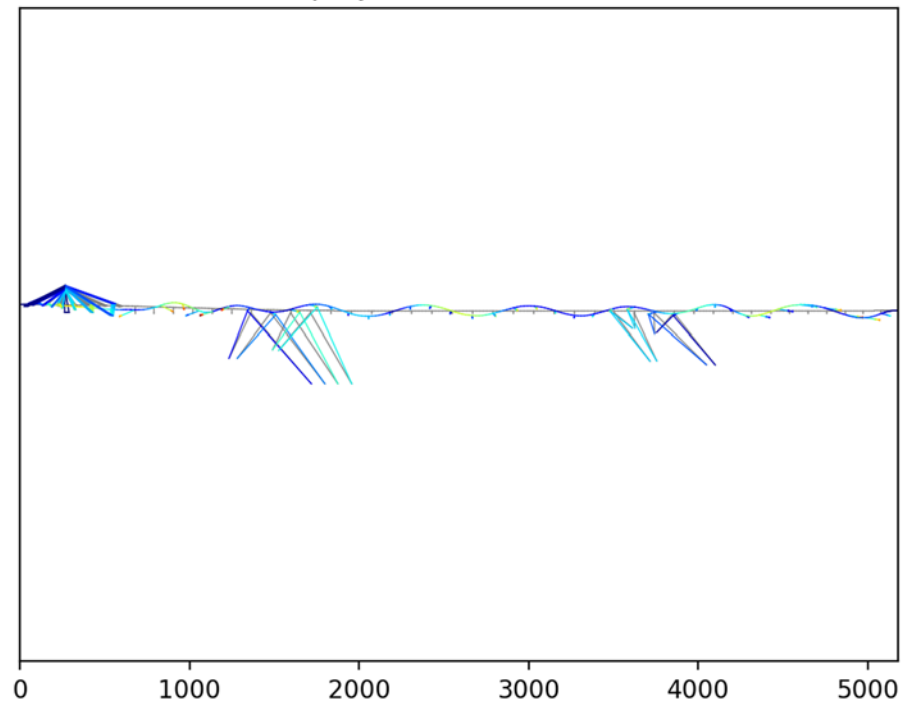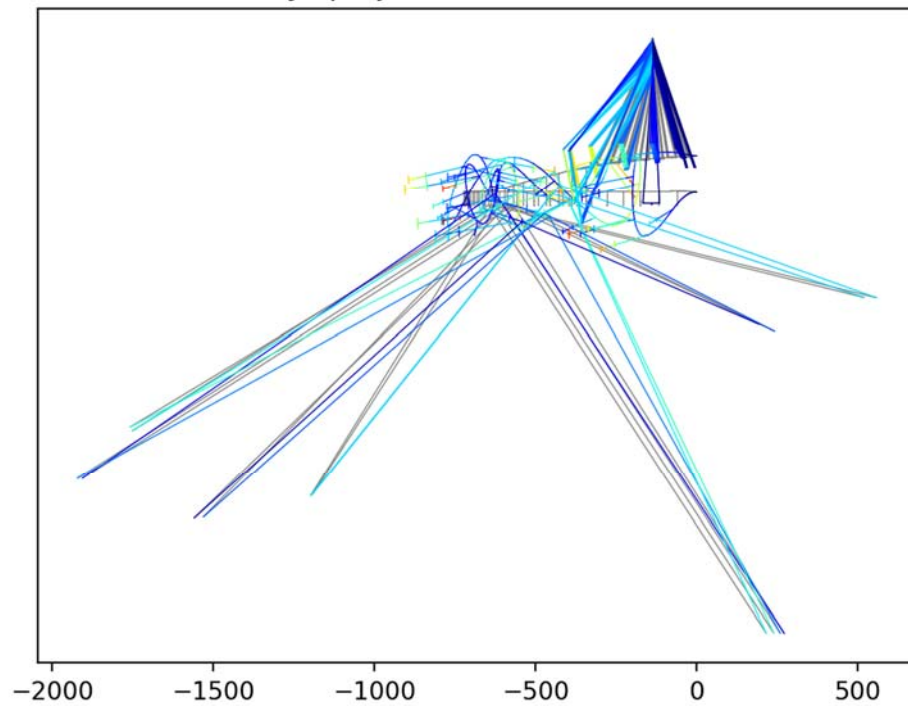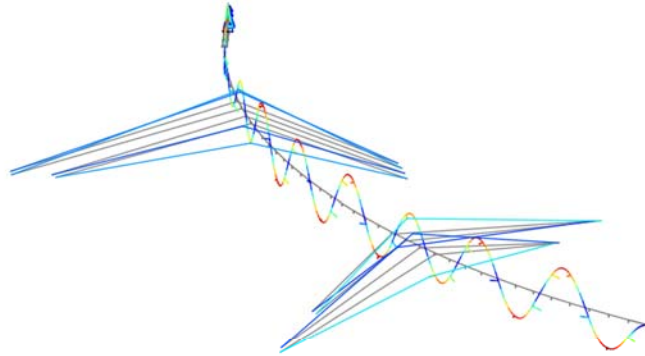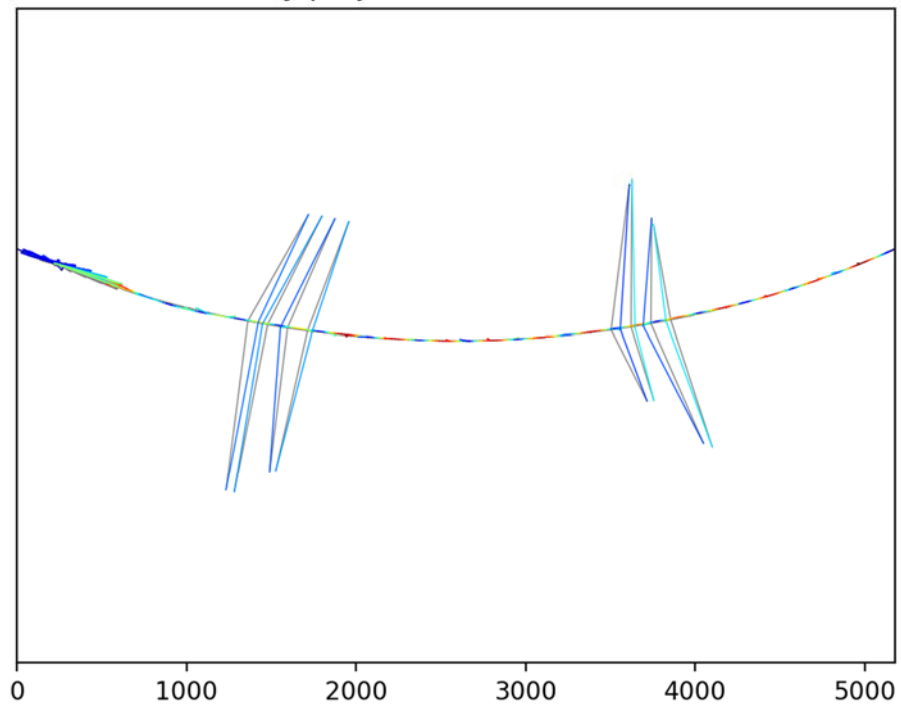xy projection for mode 10
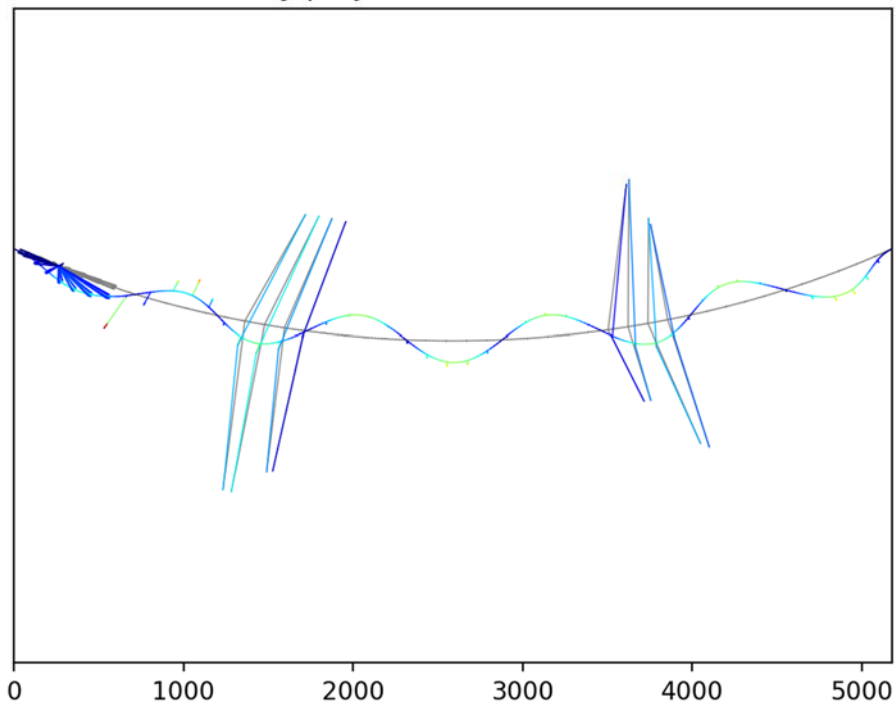
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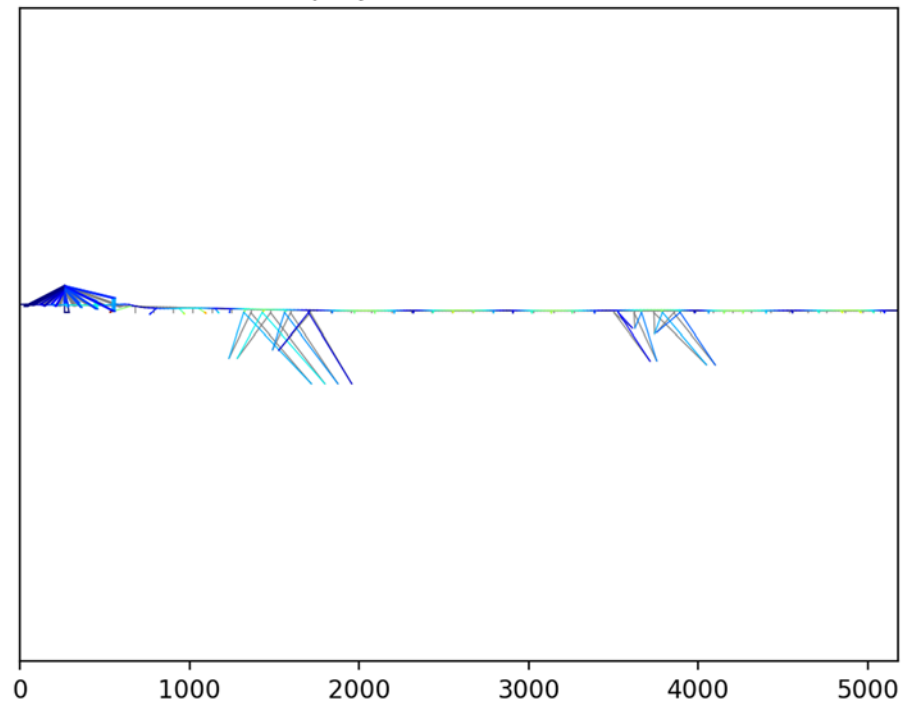
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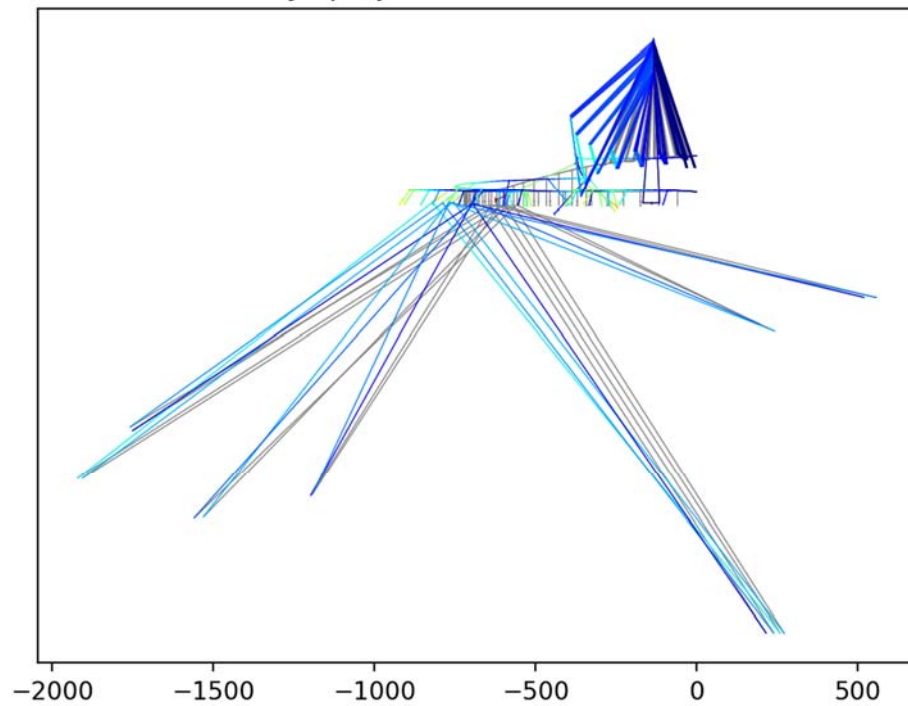
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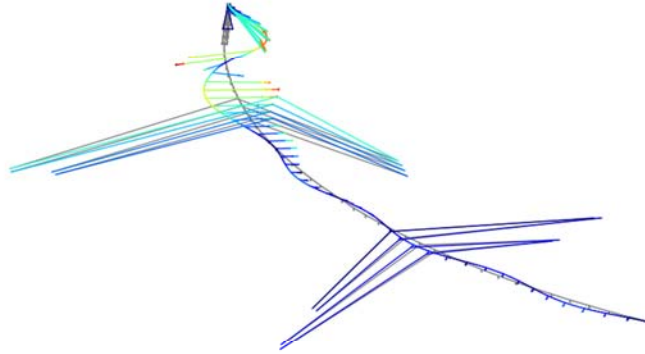
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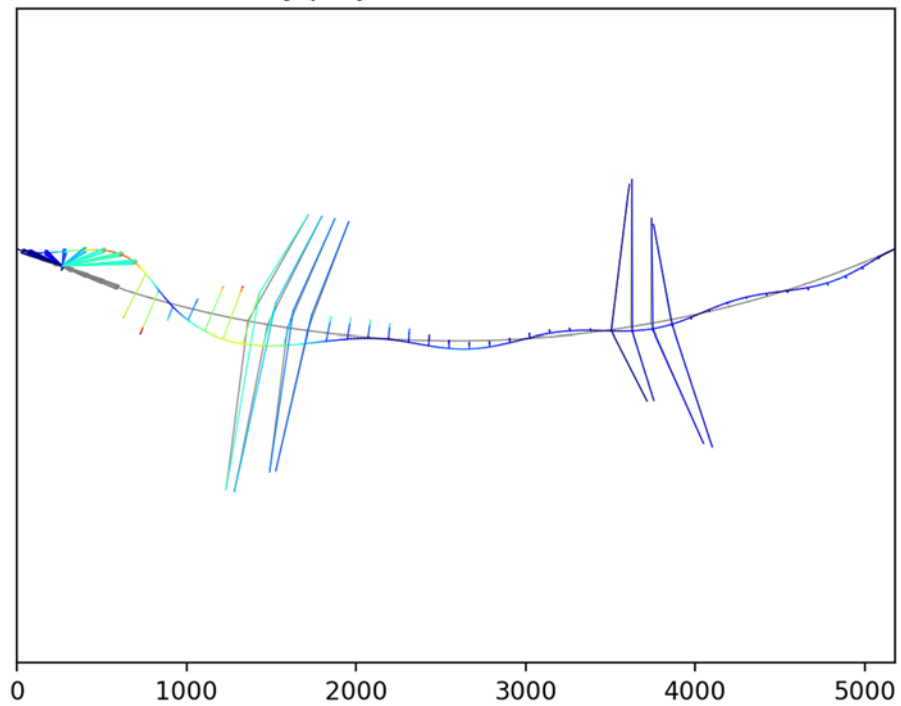
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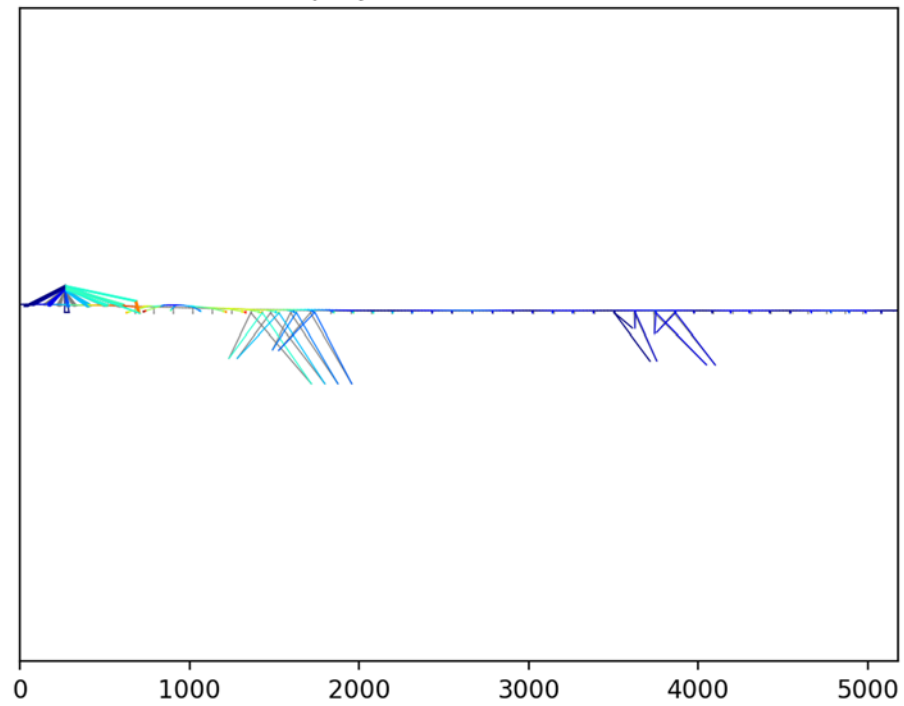
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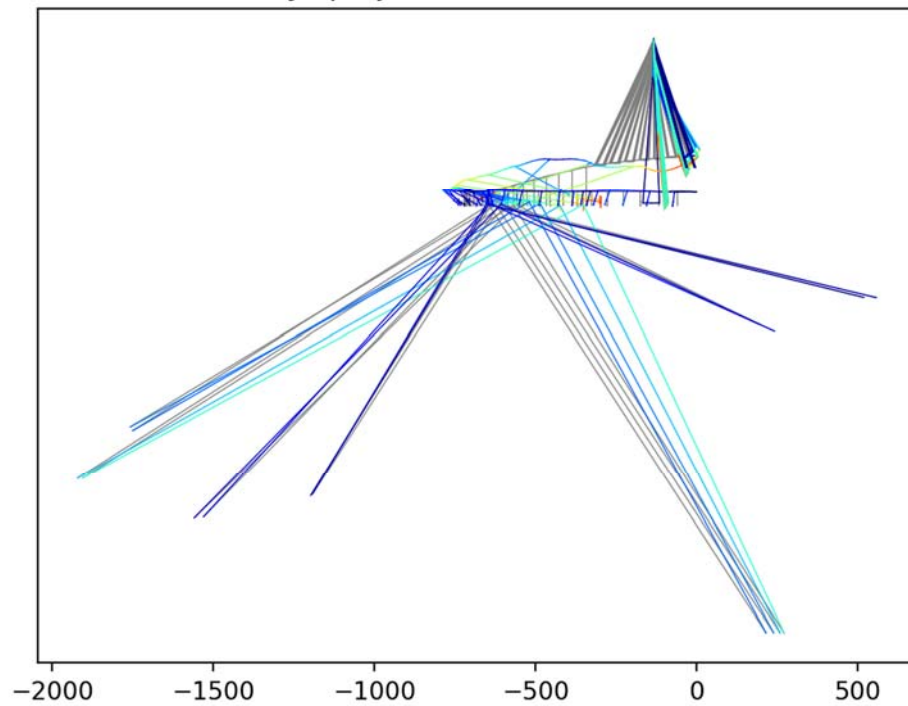
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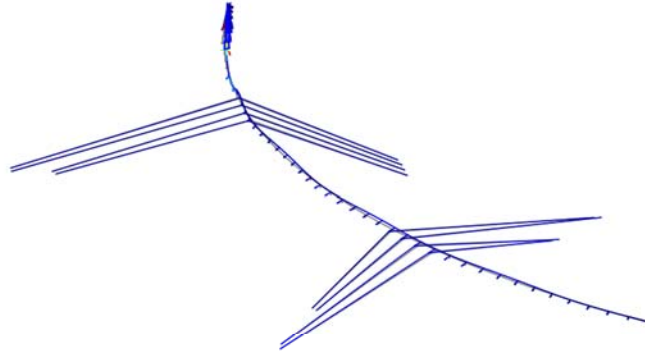
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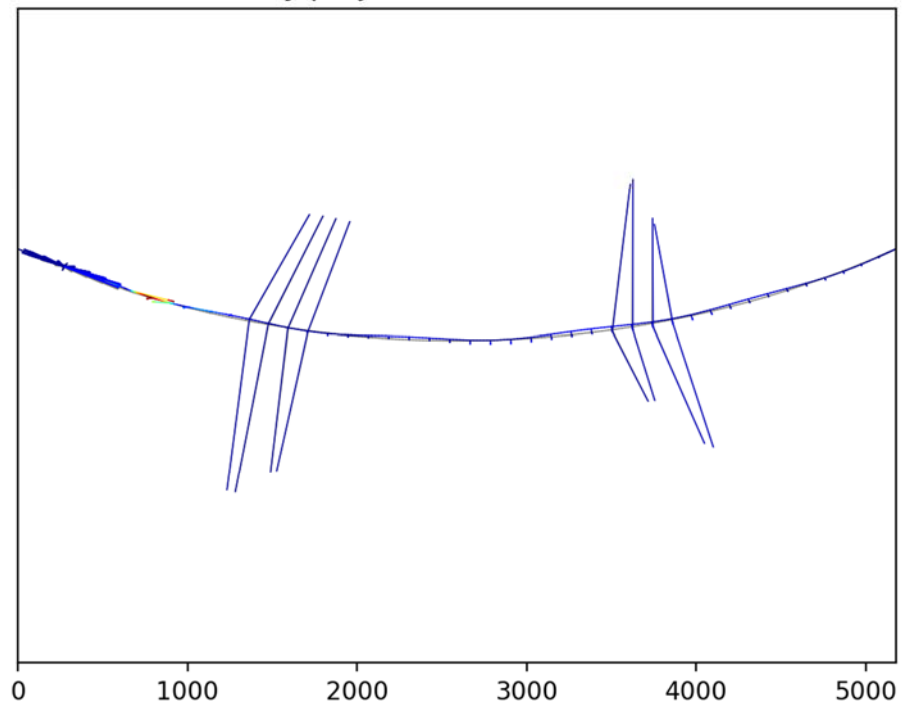
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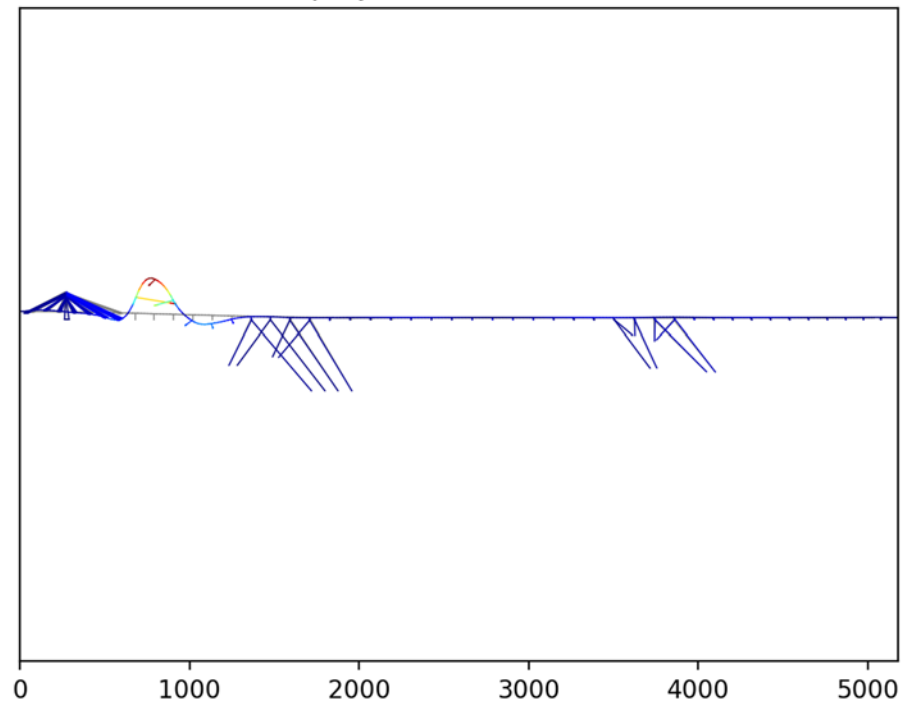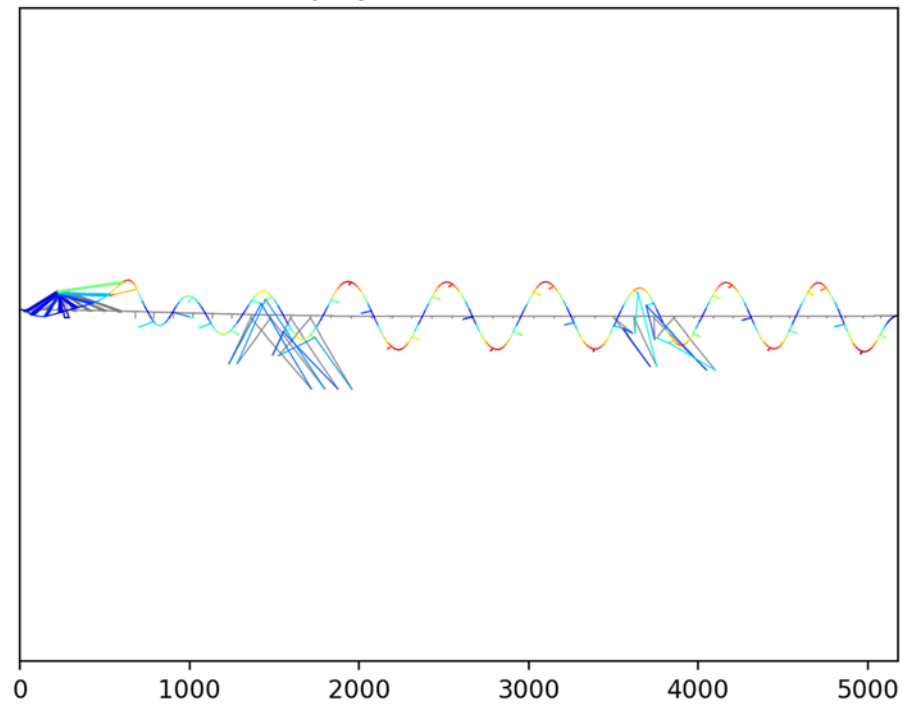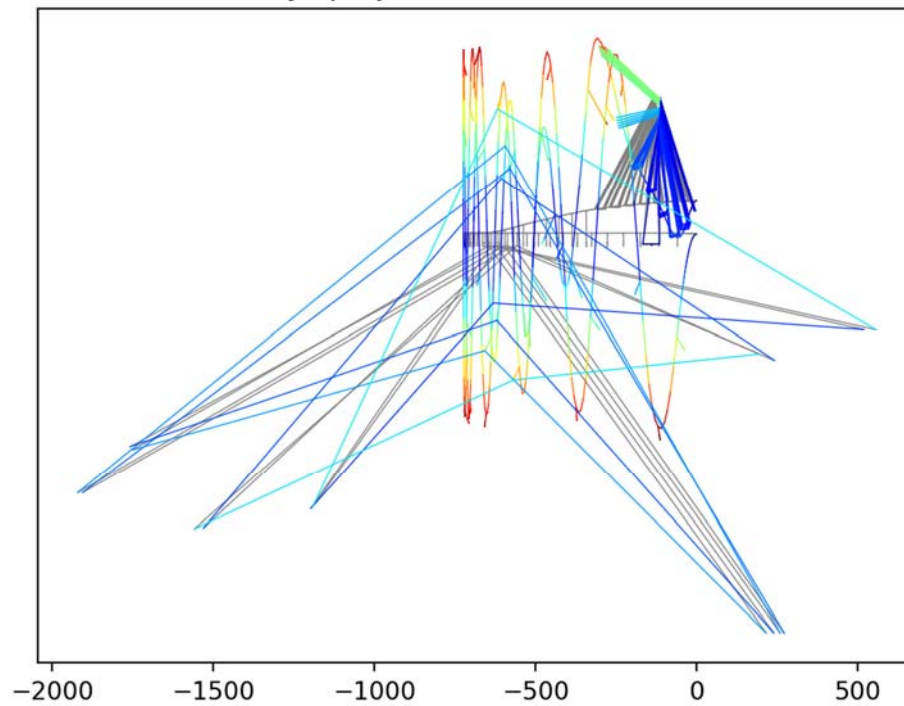

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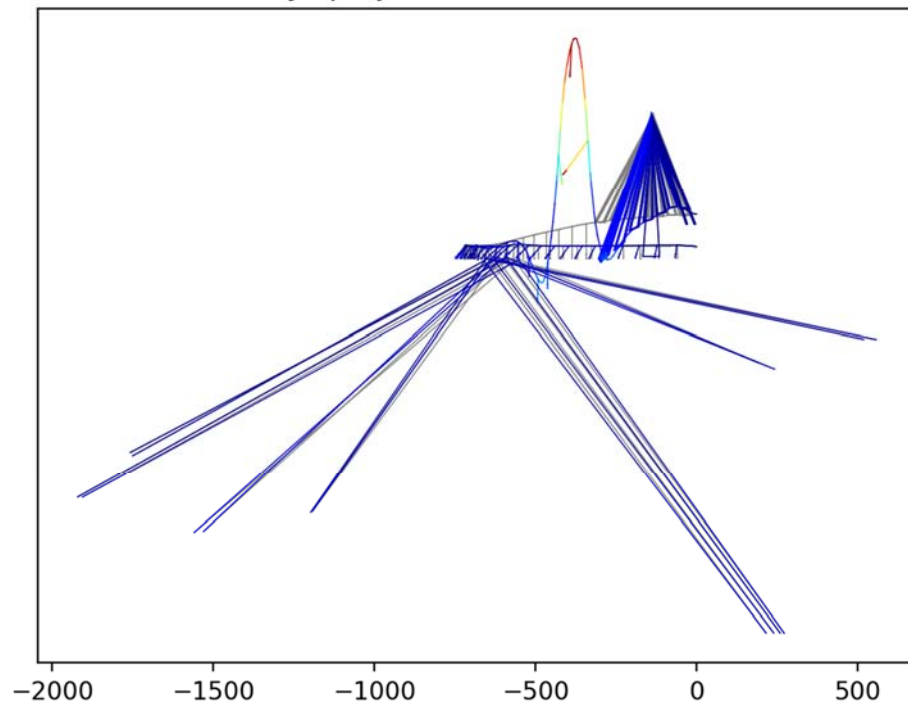
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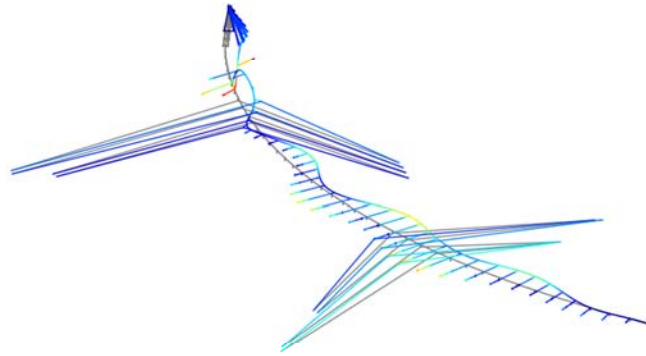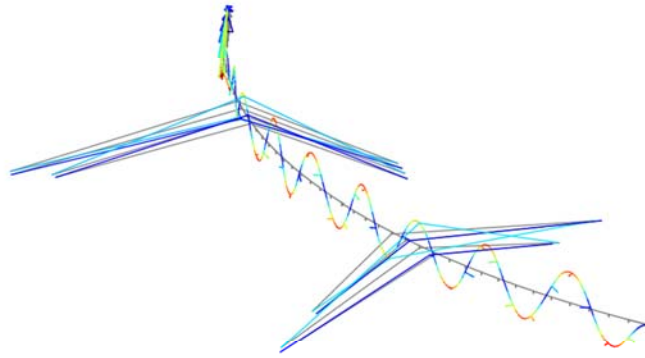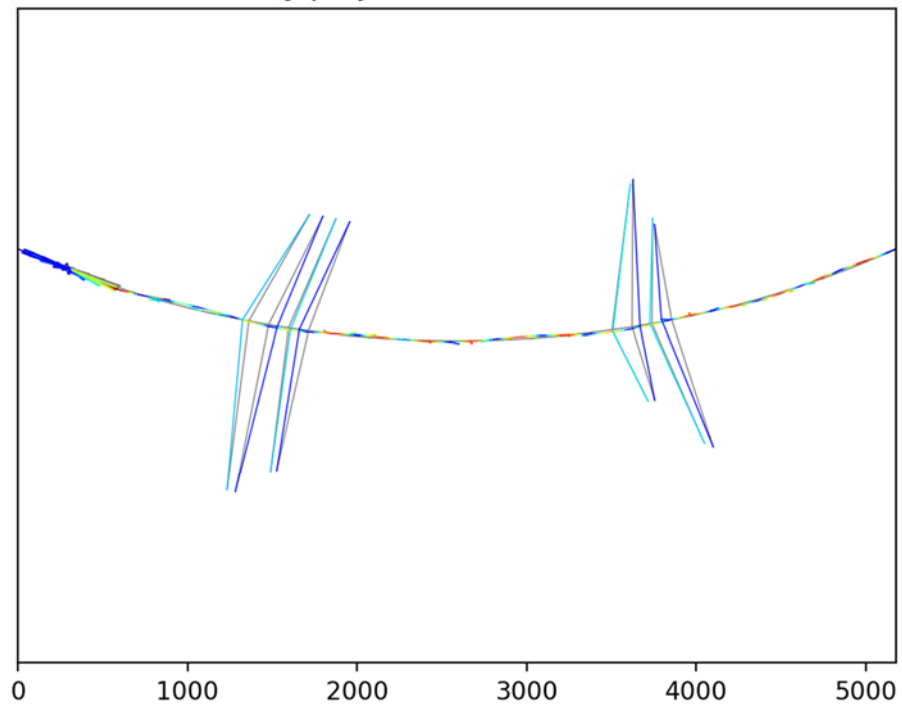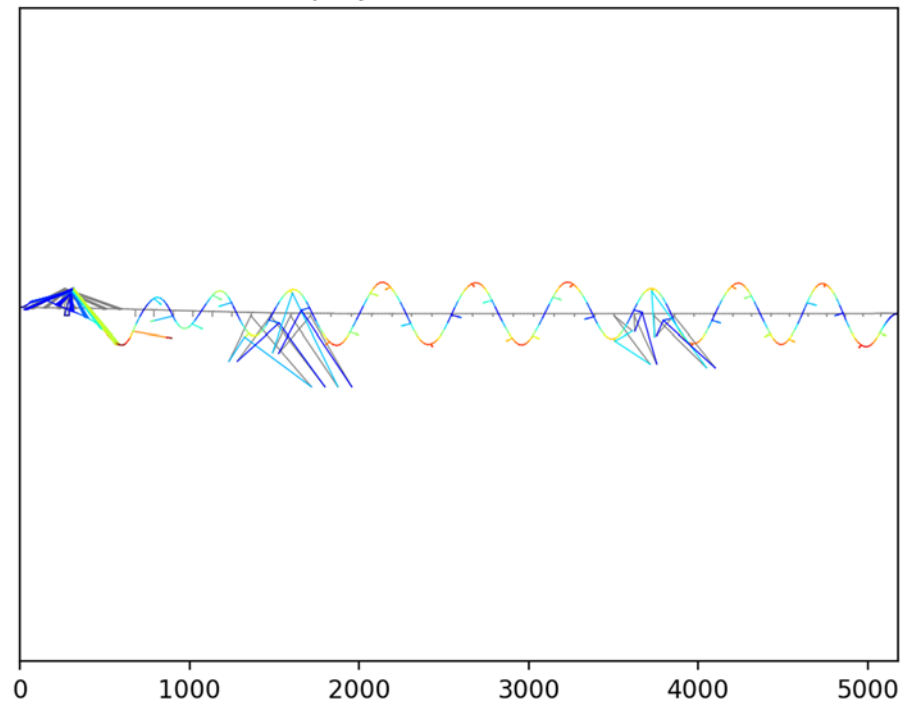

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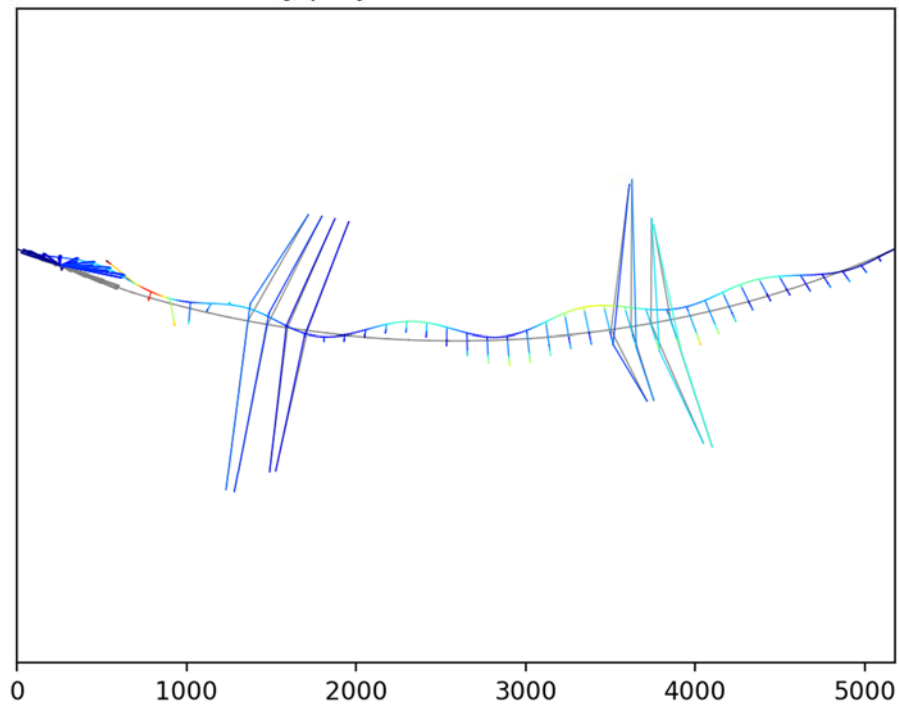
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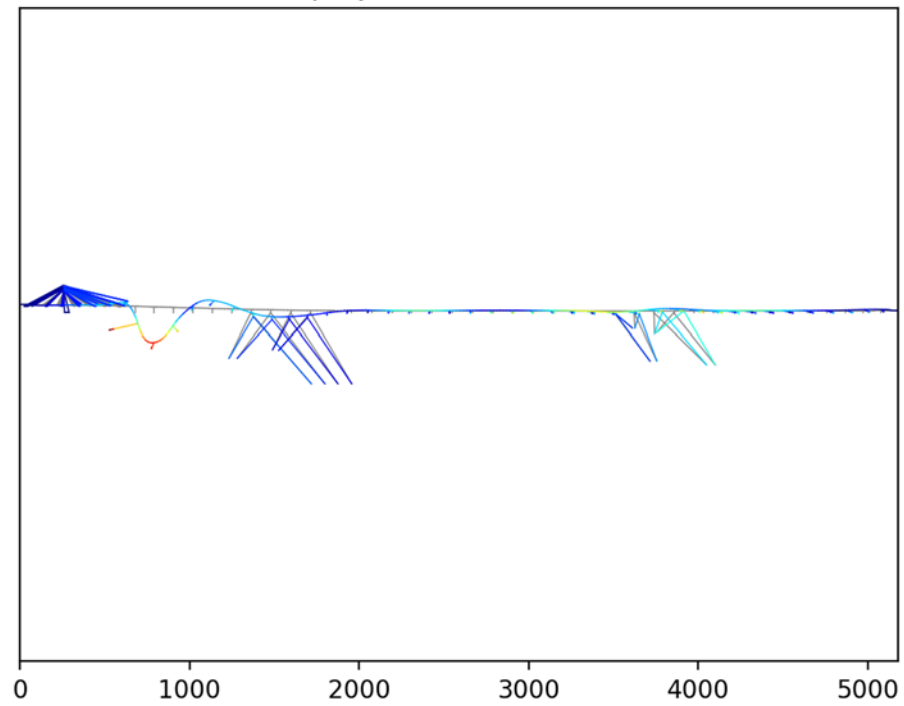
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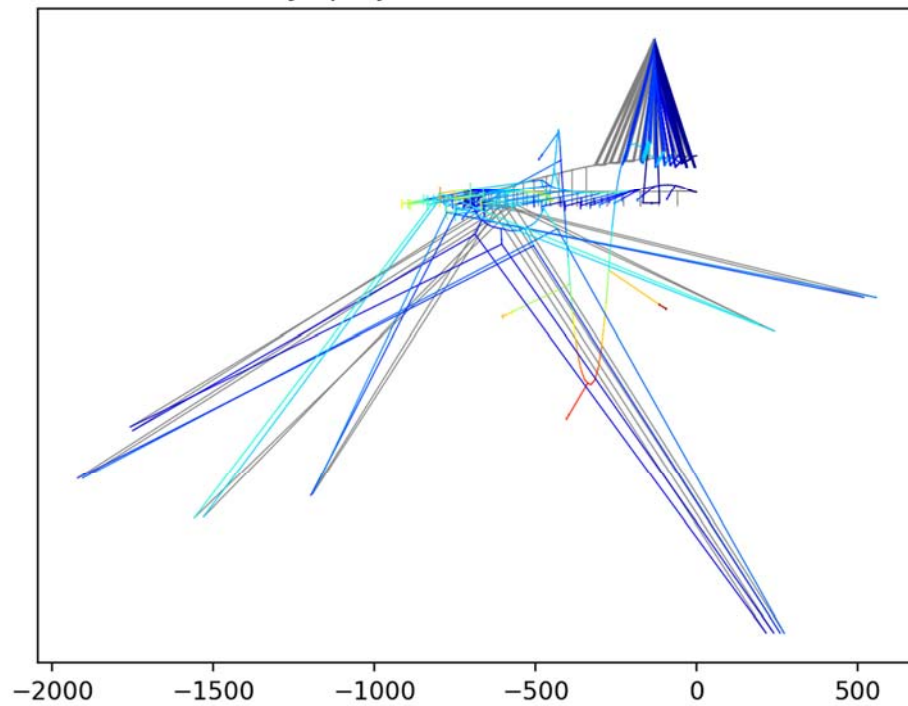
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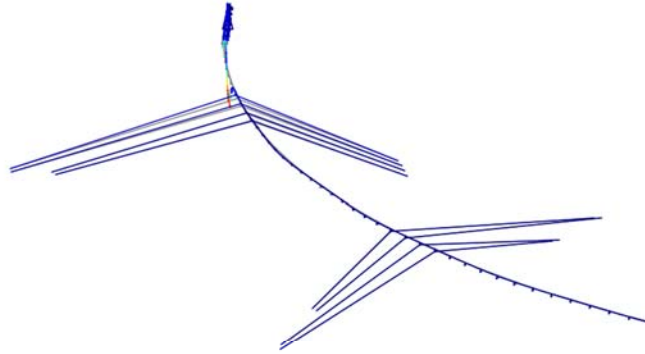
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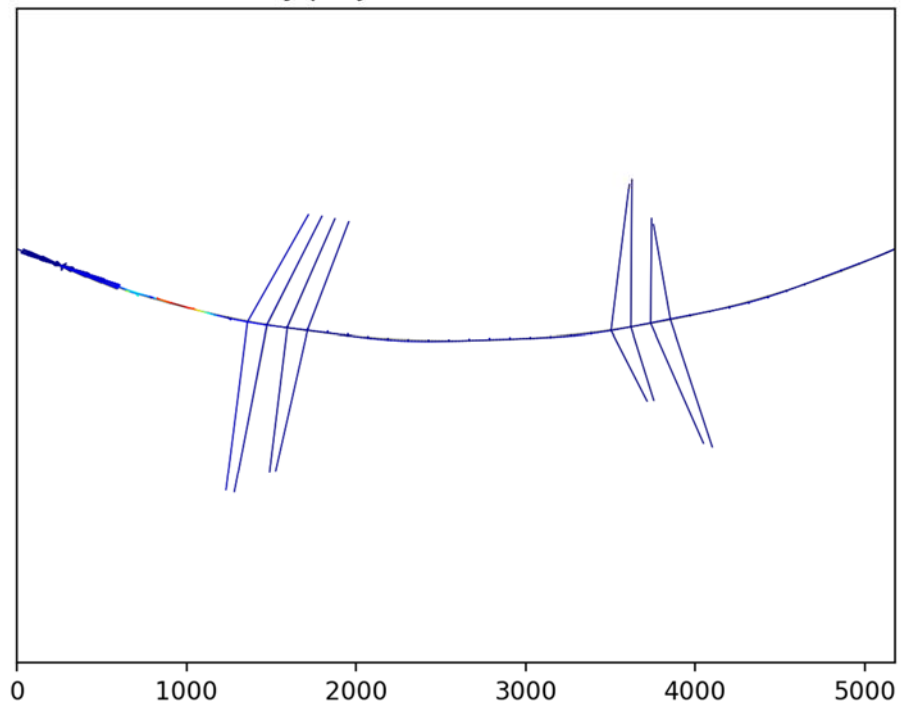
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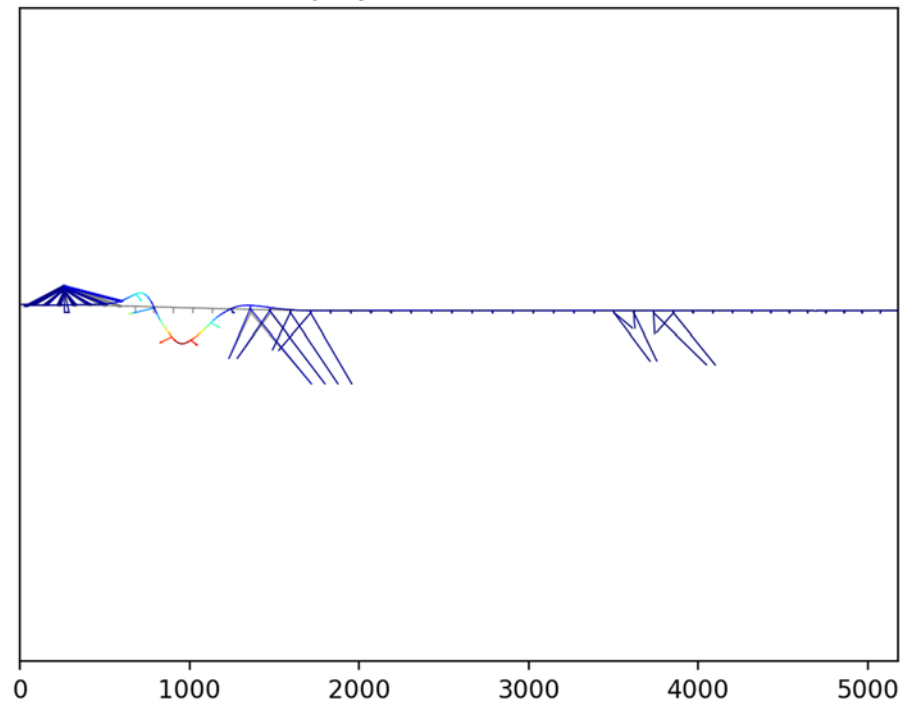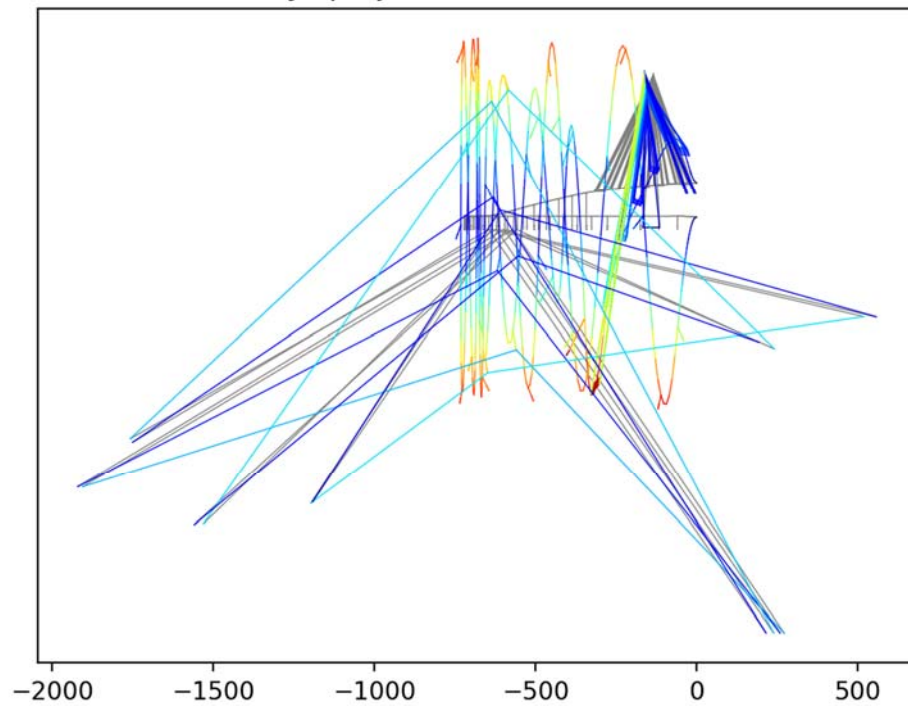

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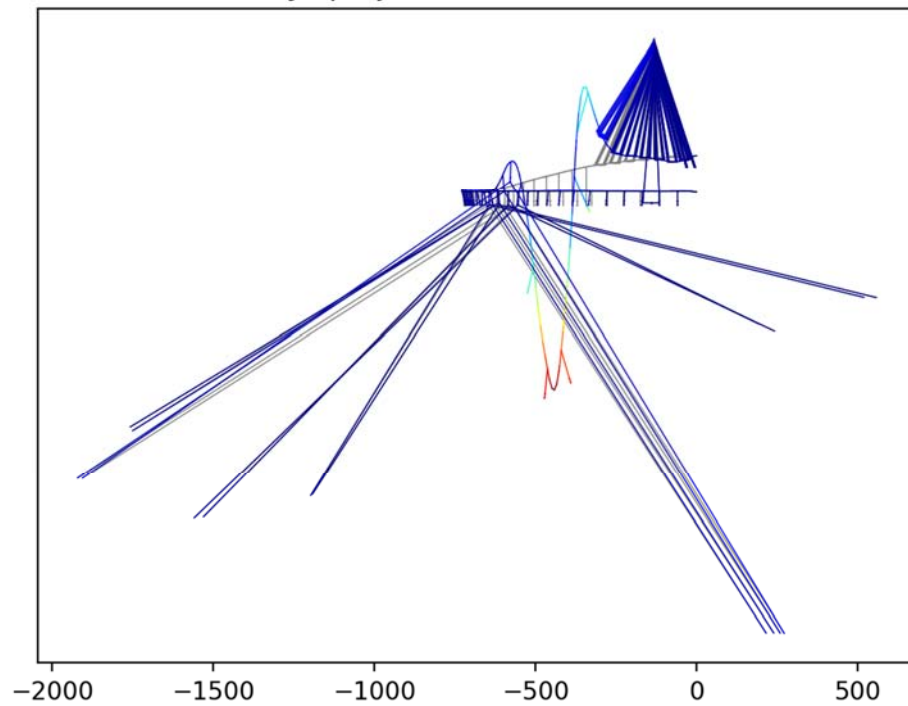
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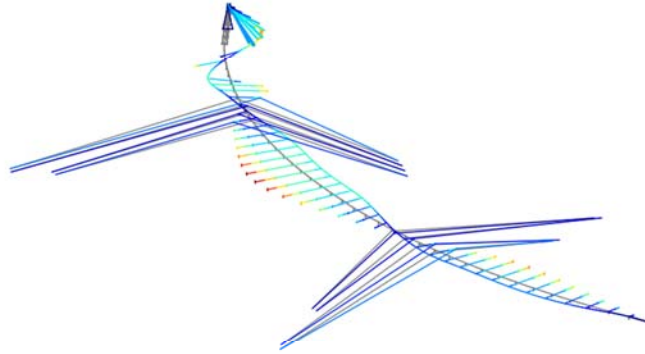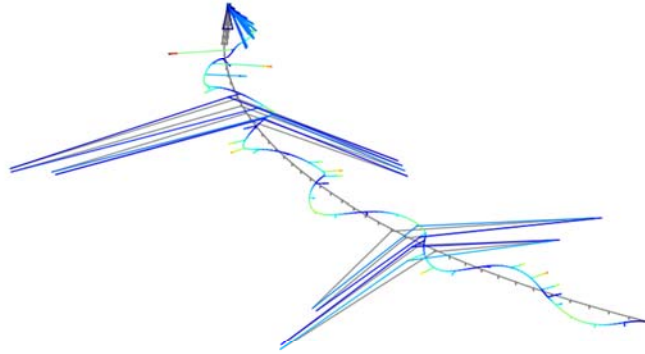

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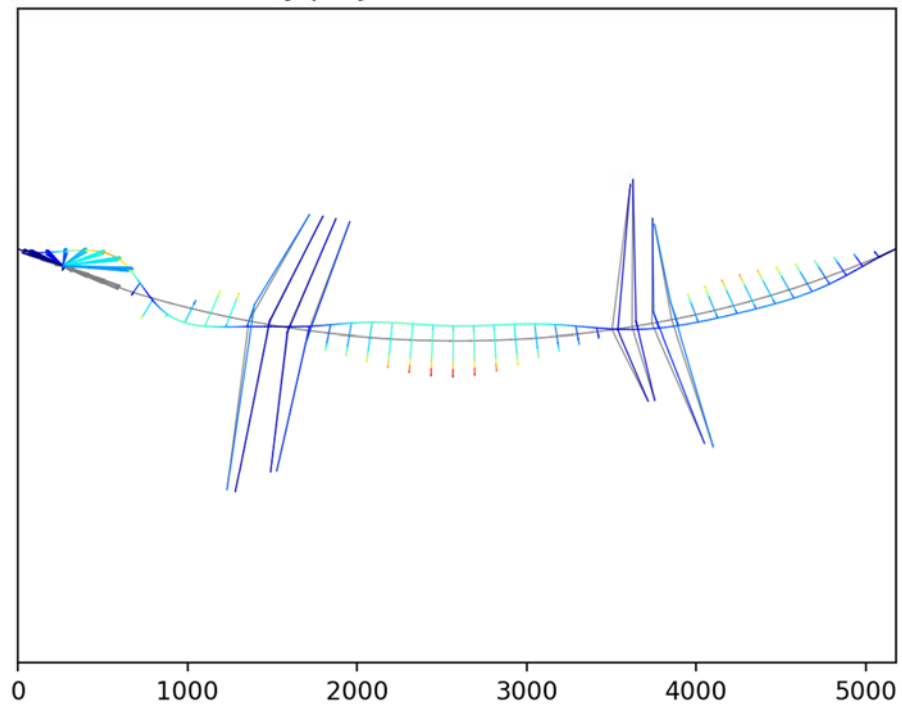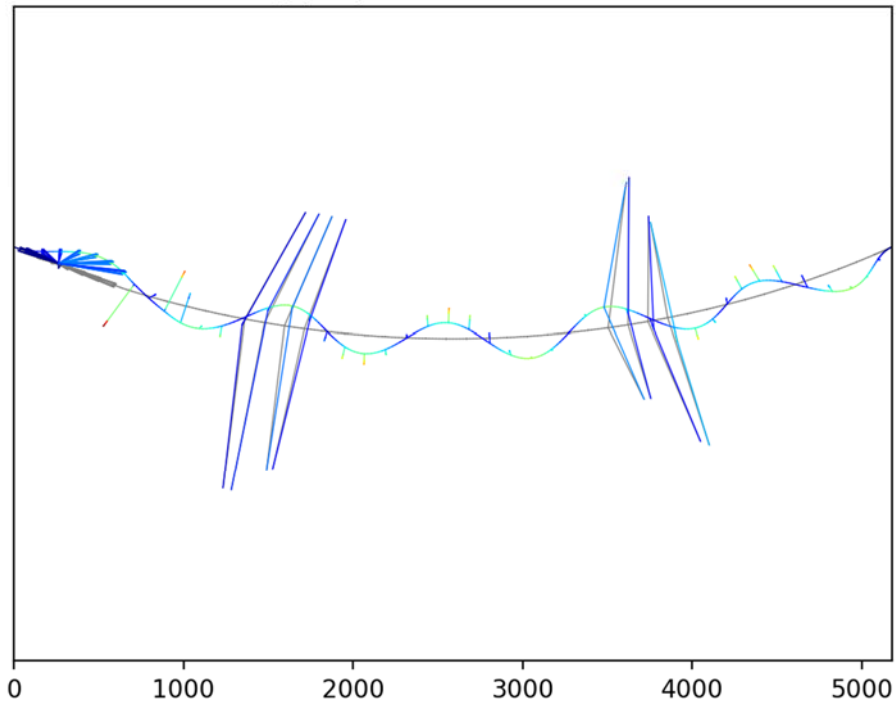
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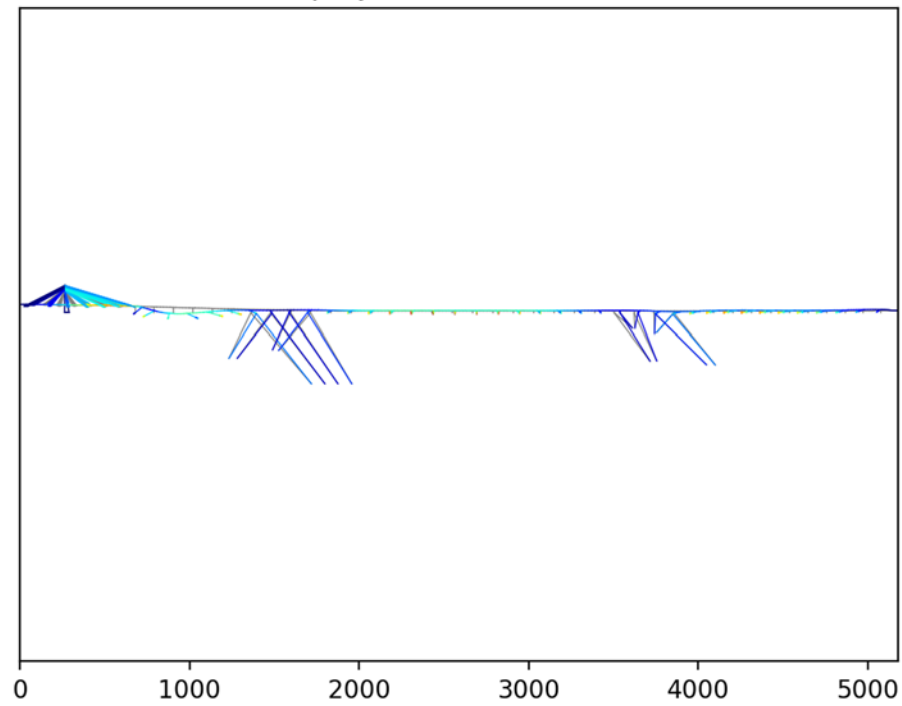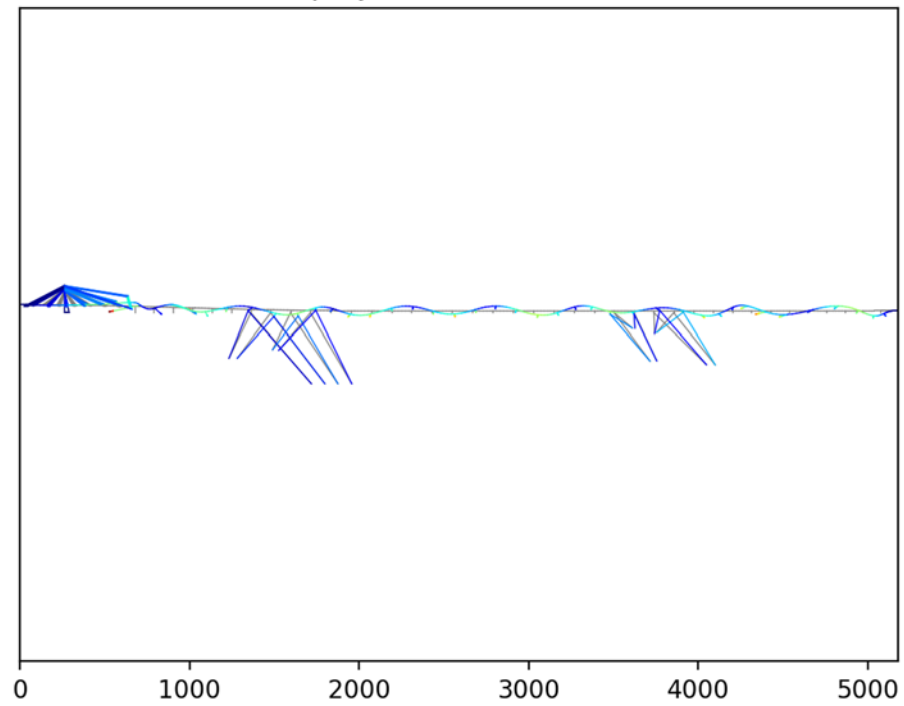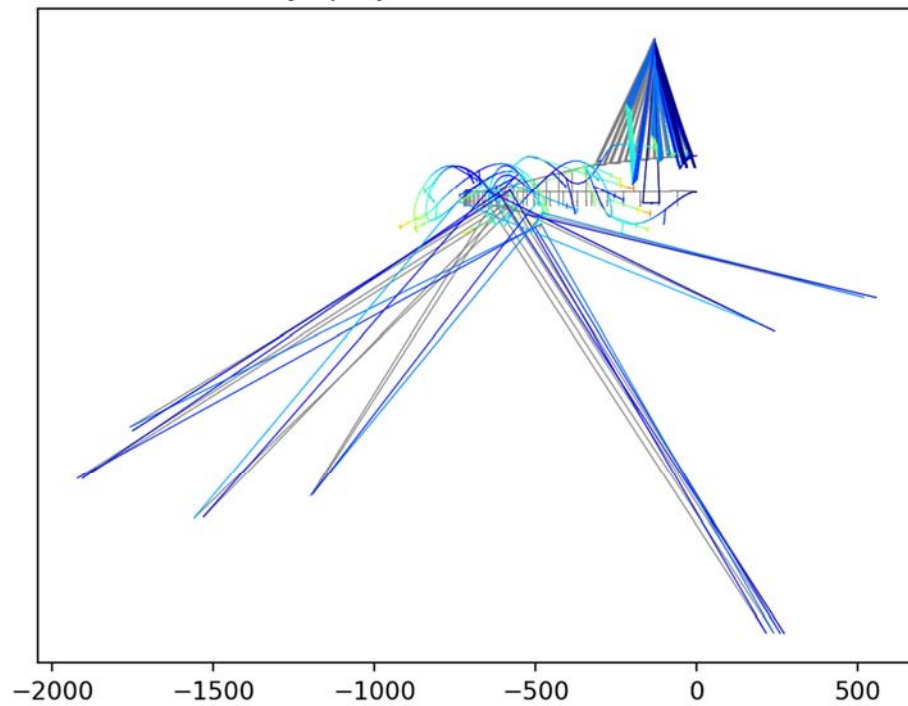

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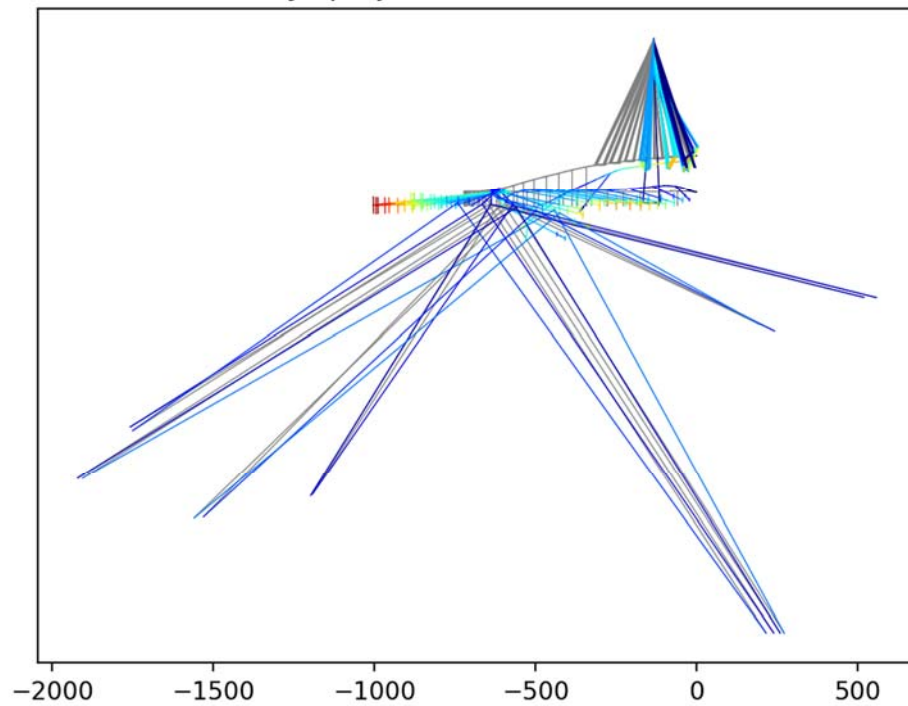
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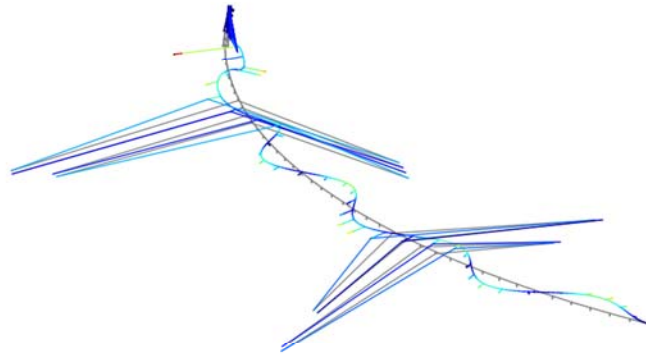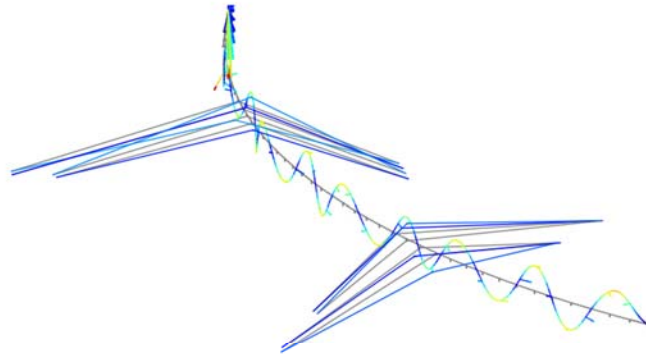

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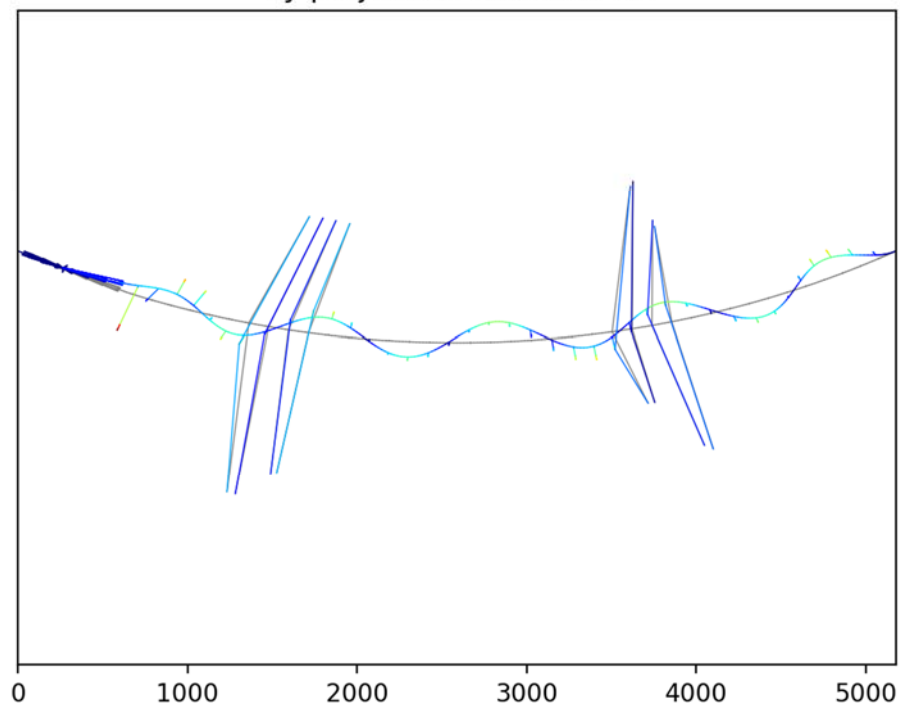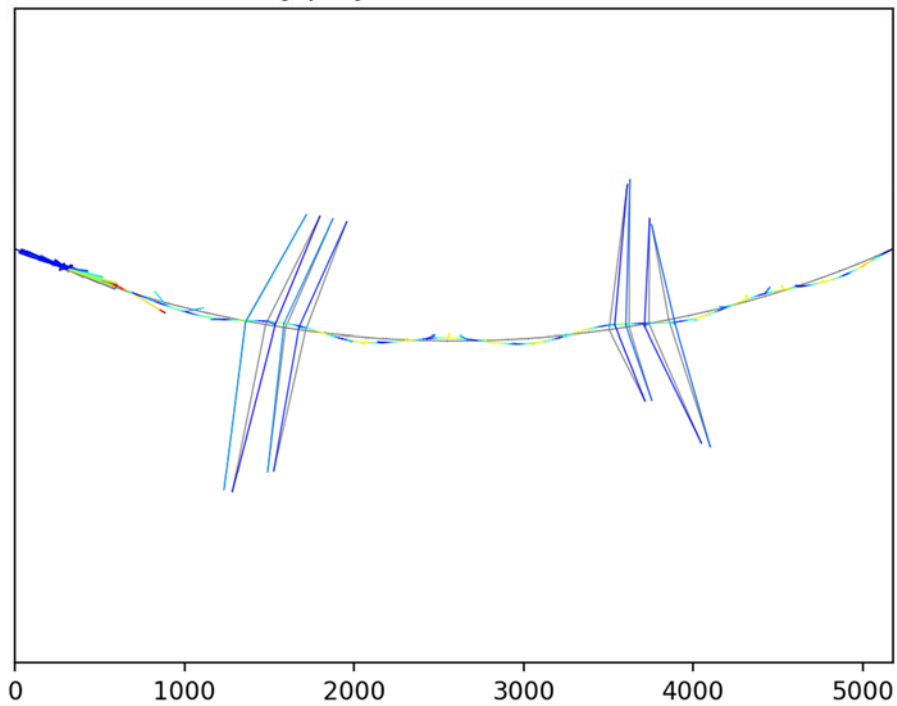
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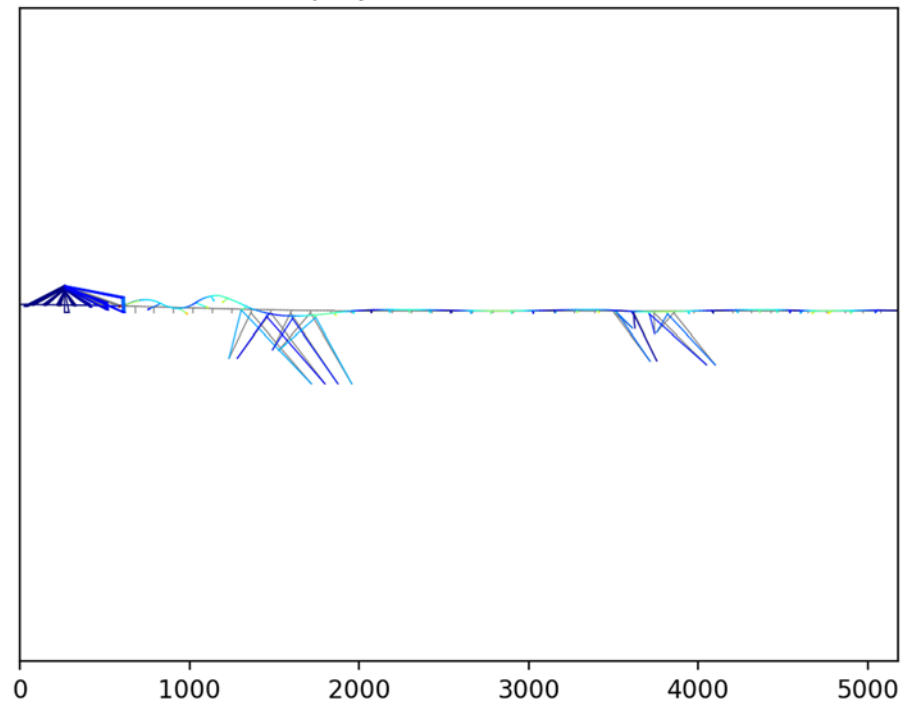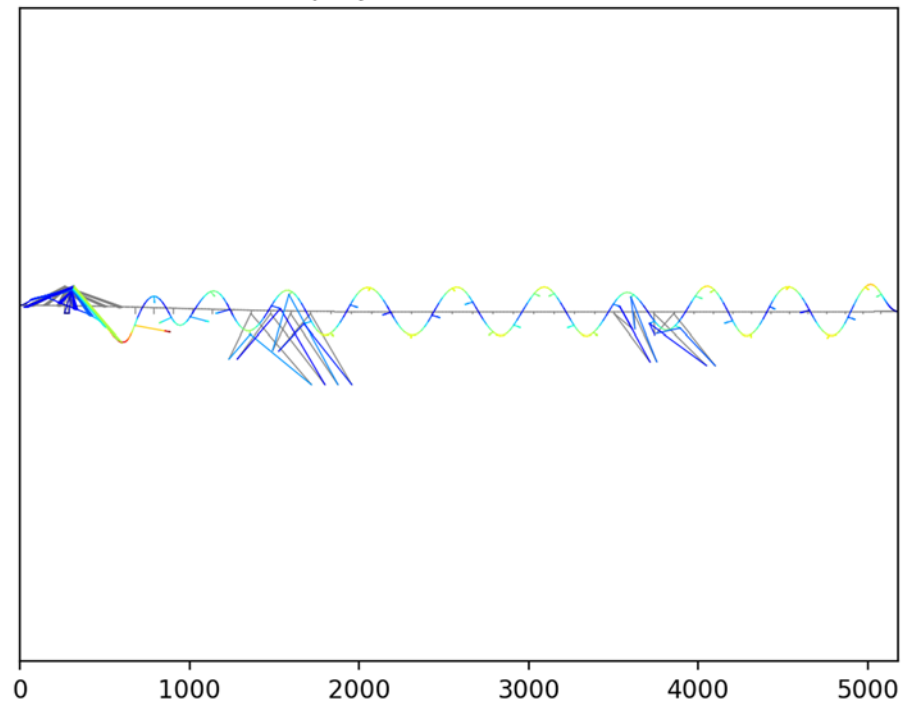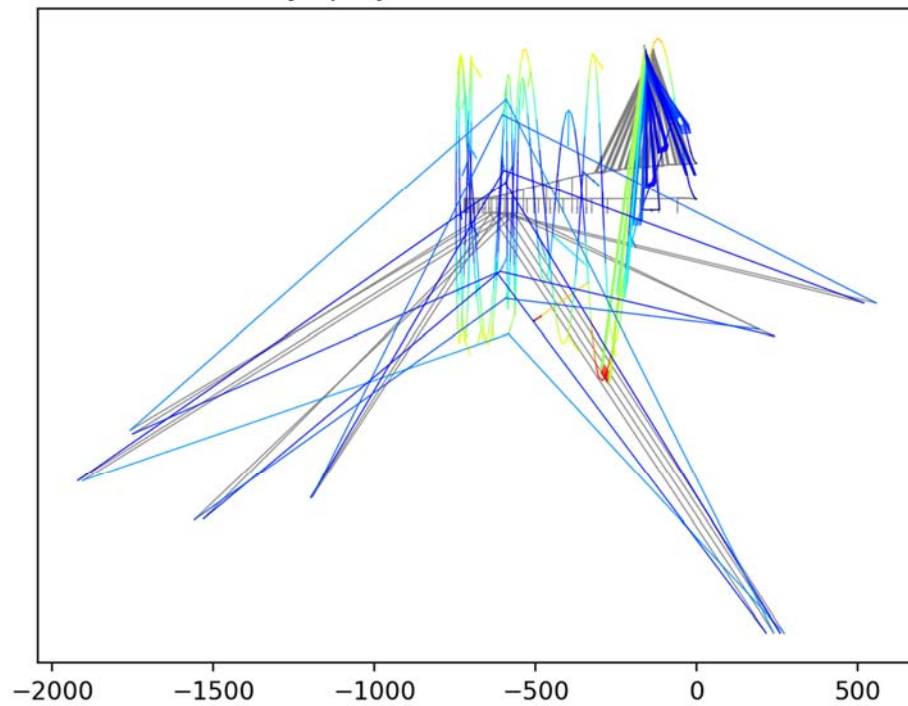

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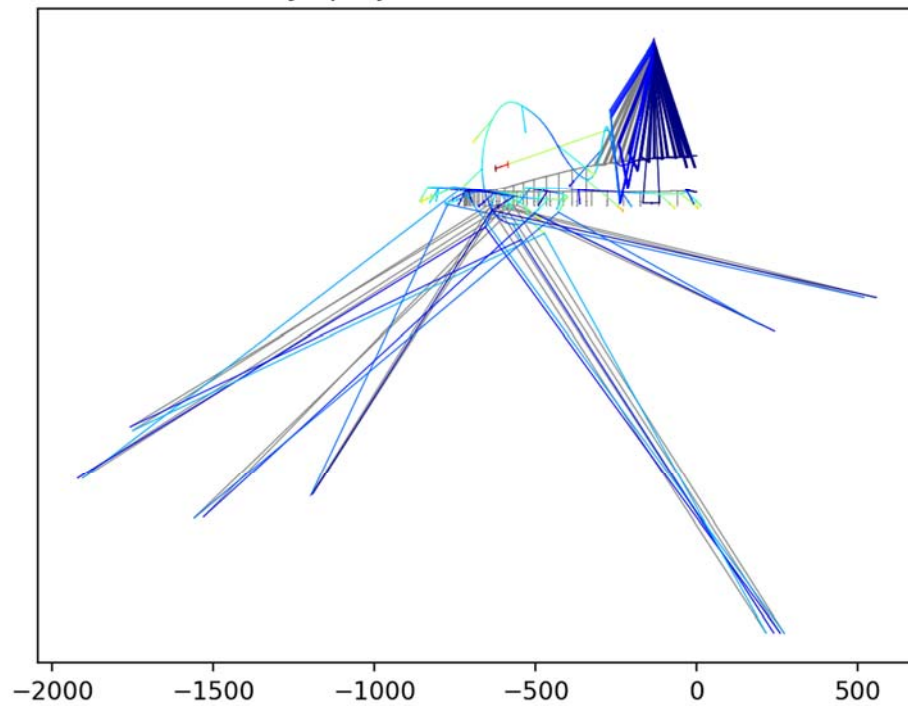
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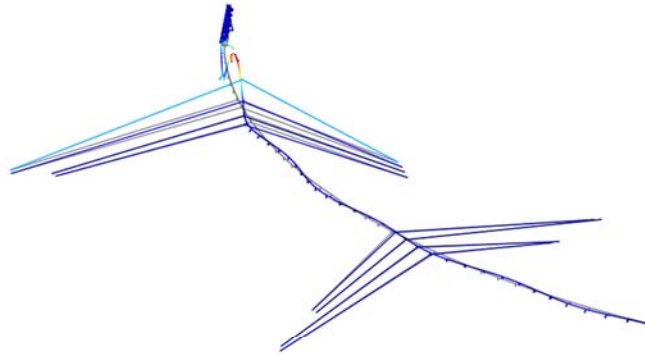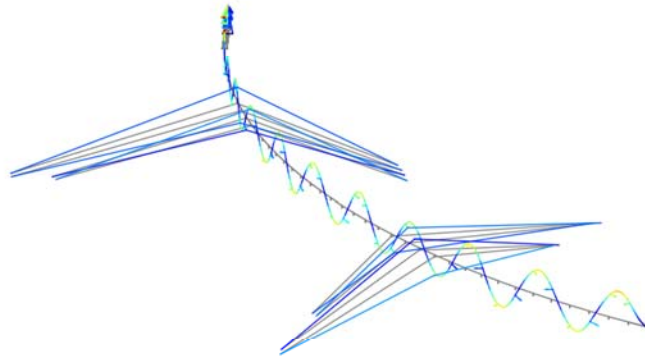

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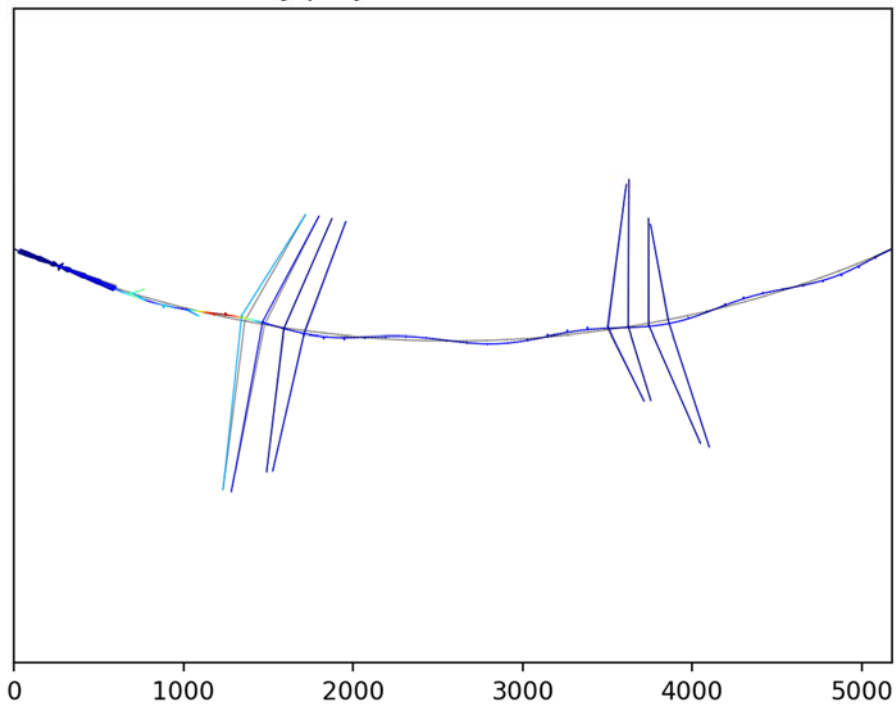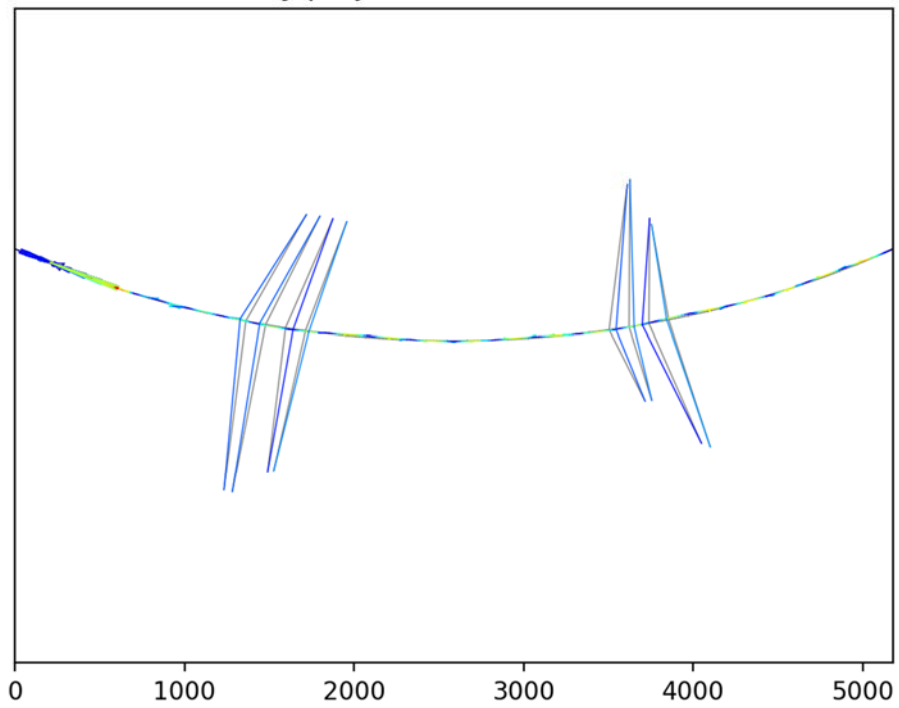
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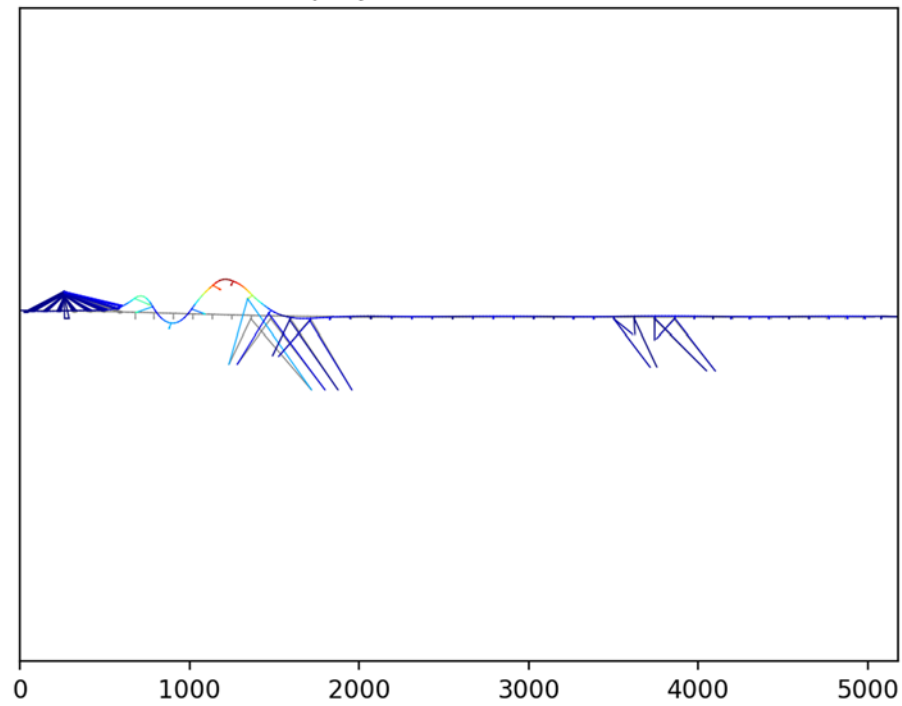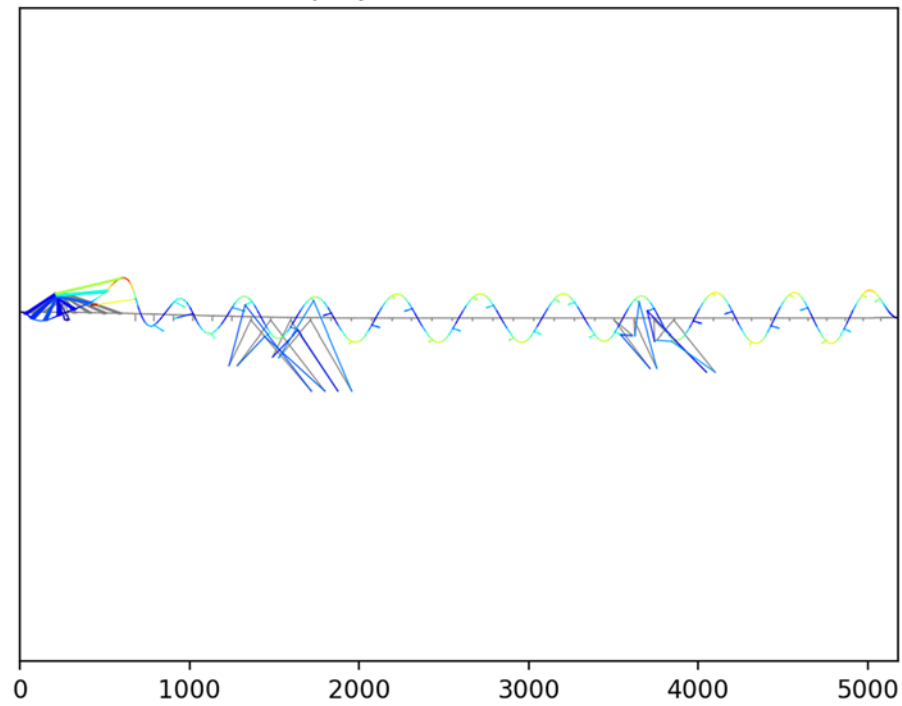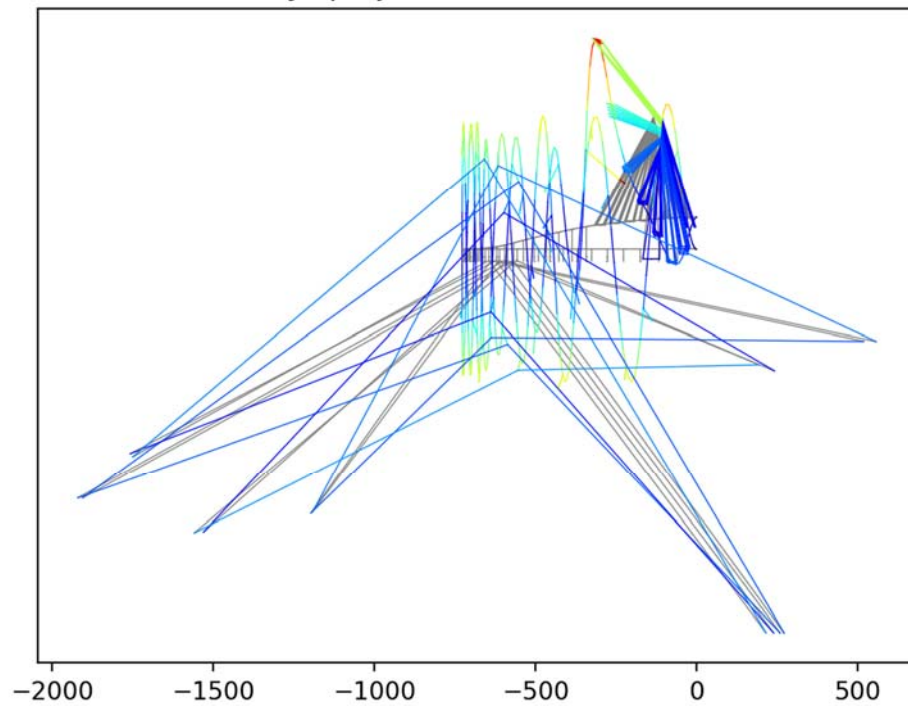

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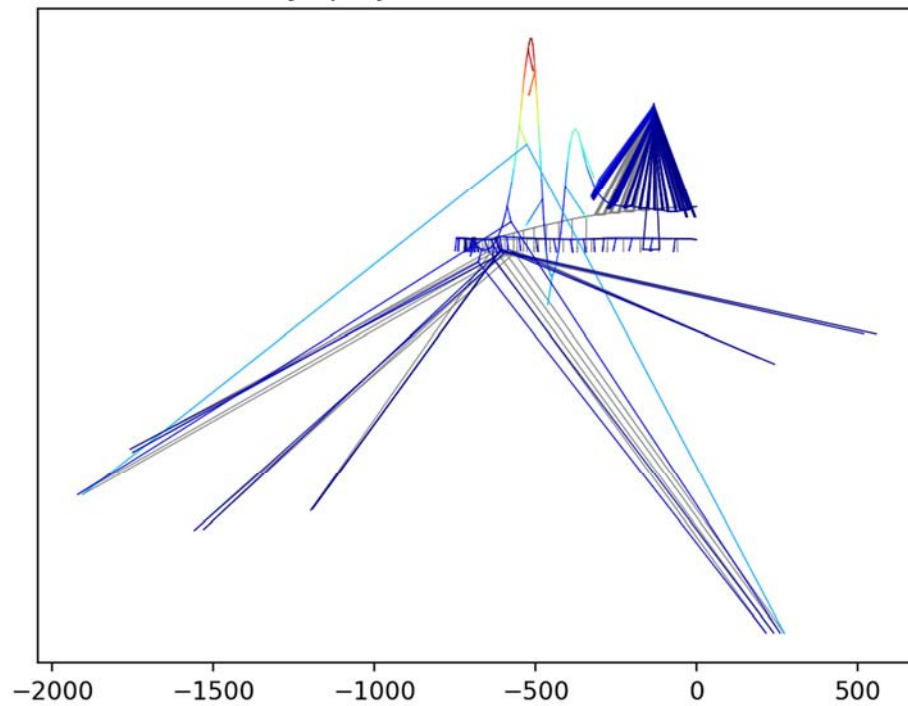
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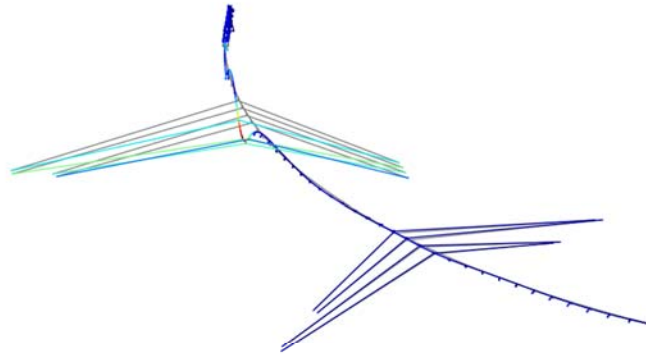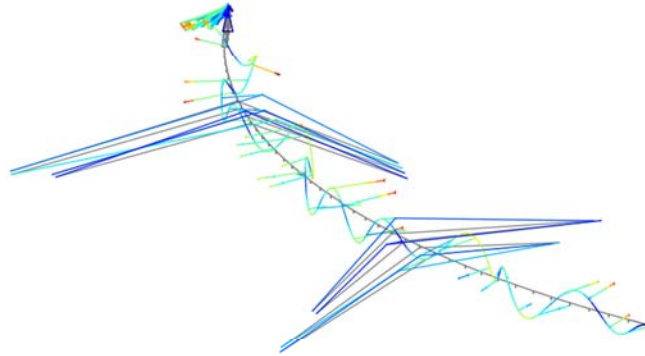

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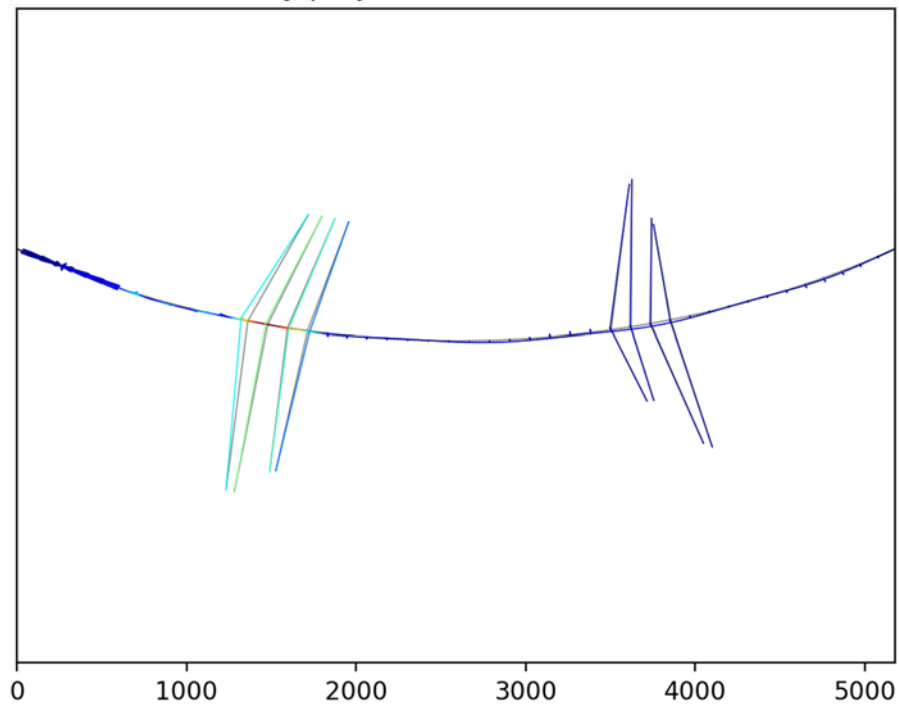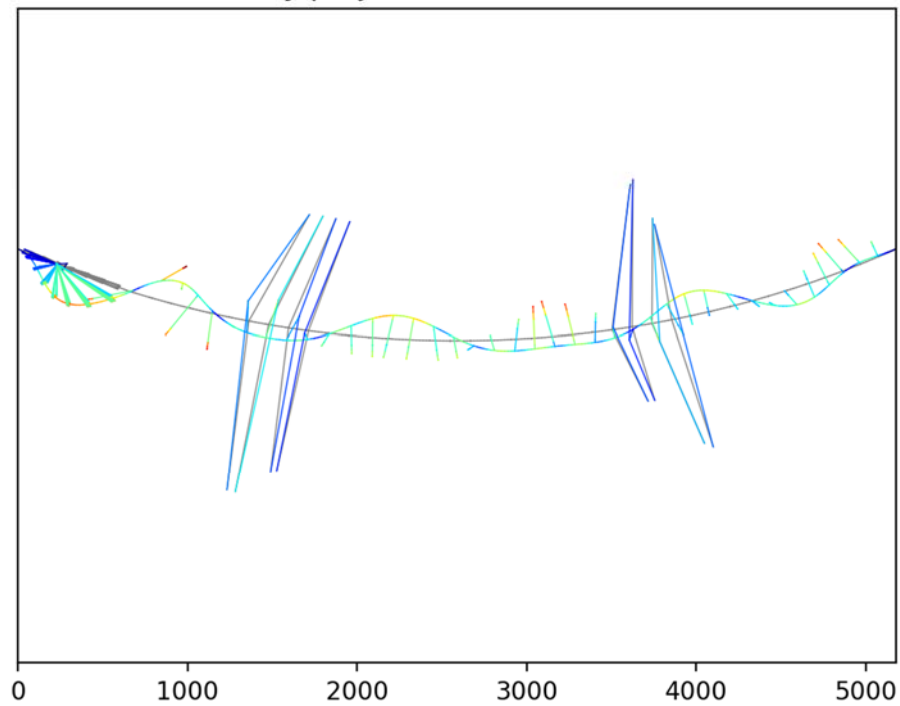
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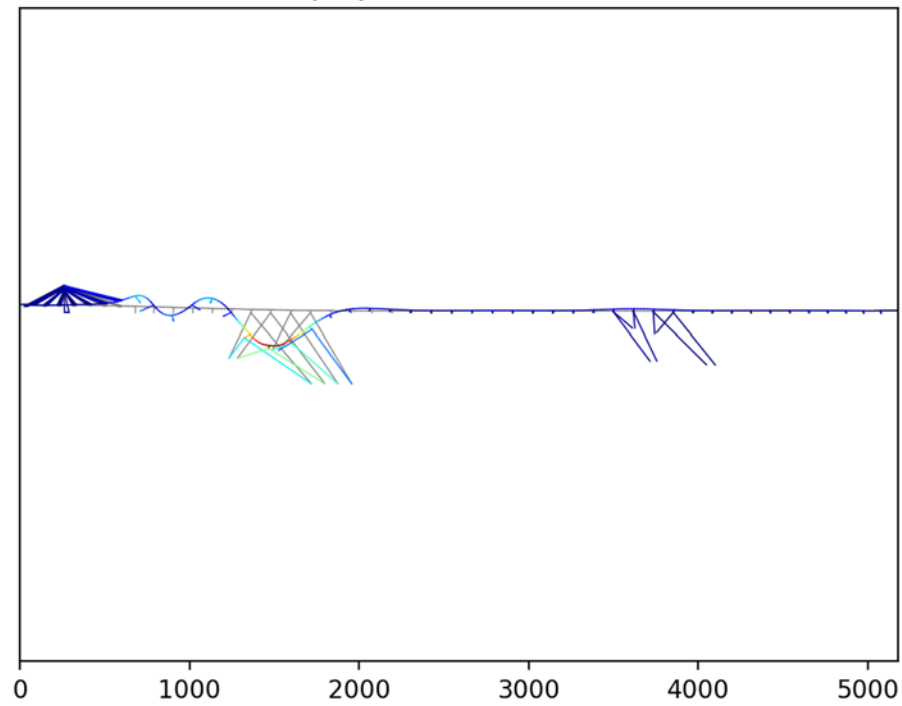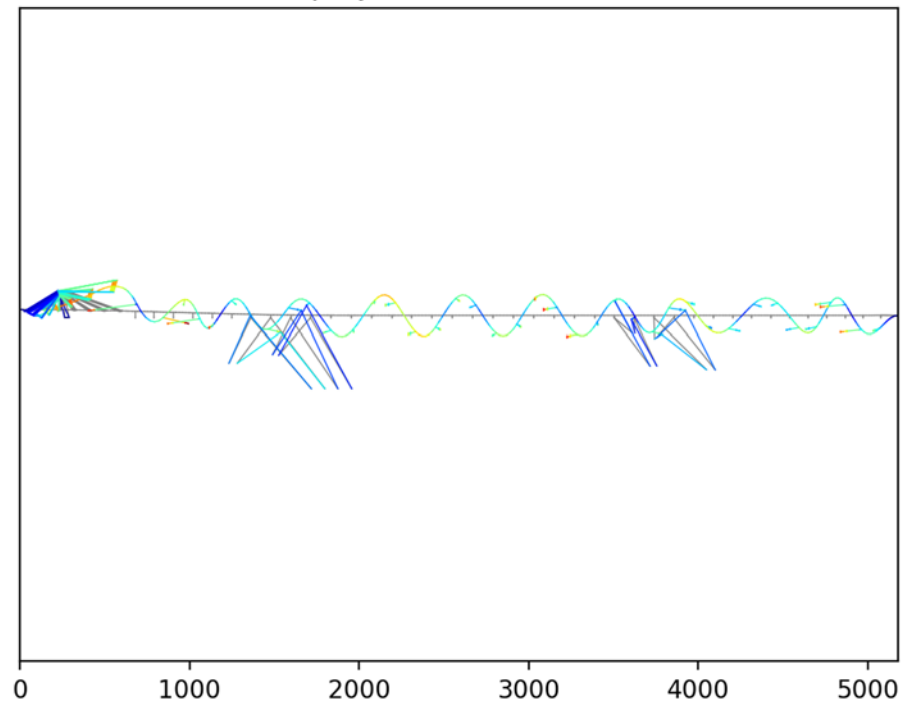

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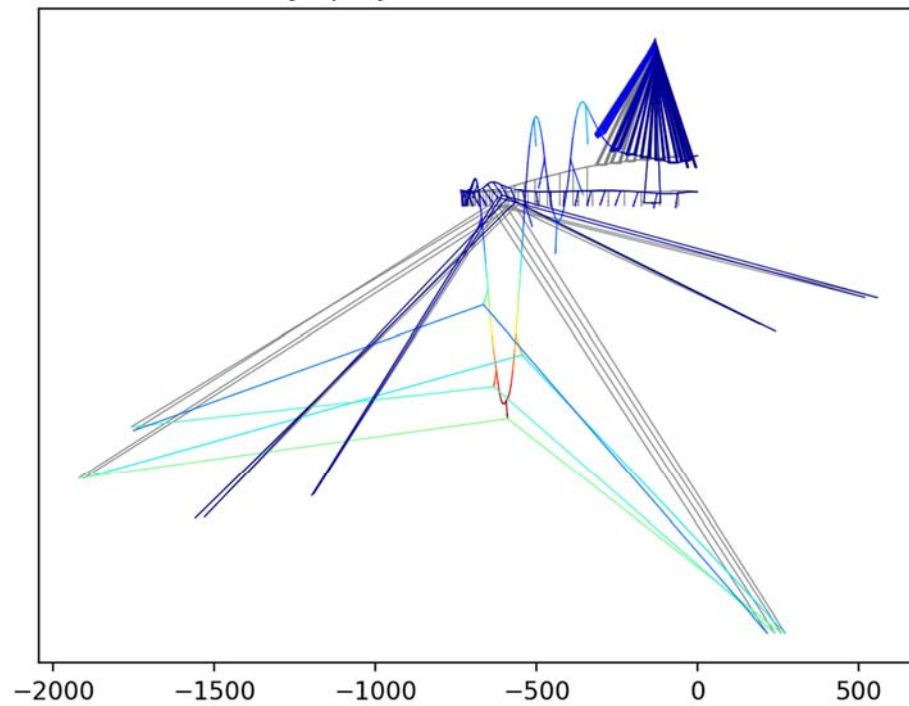
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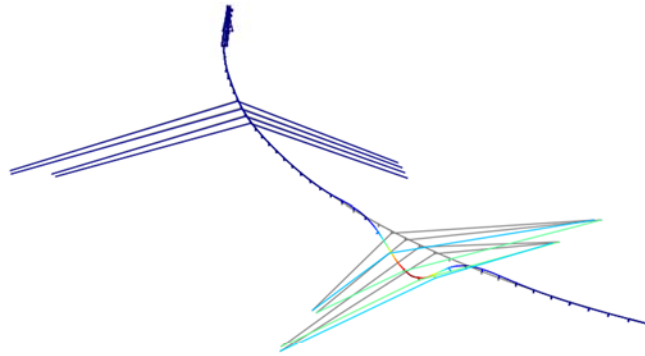
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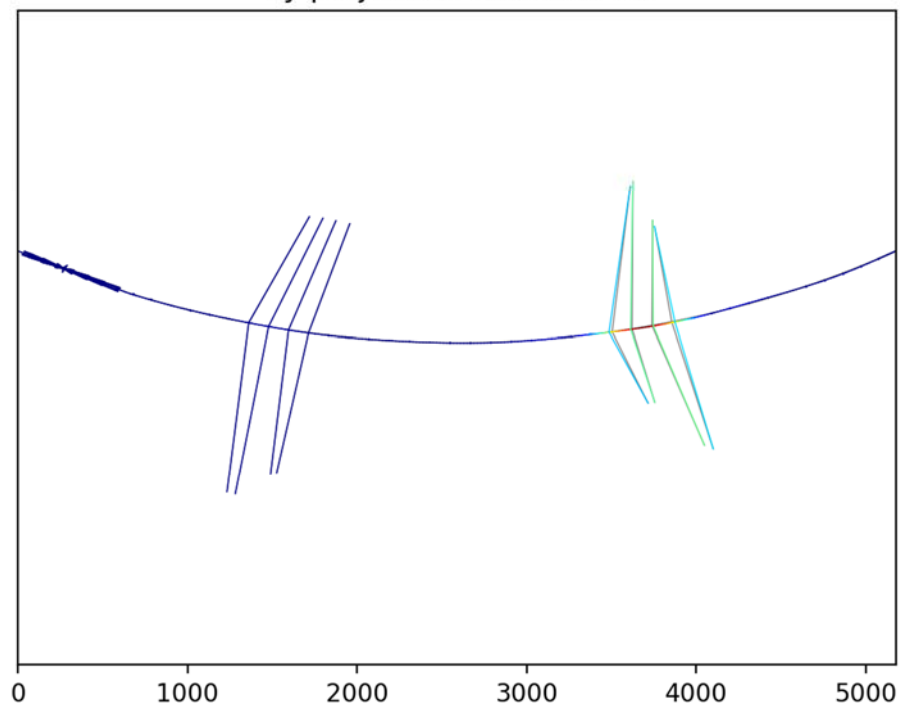
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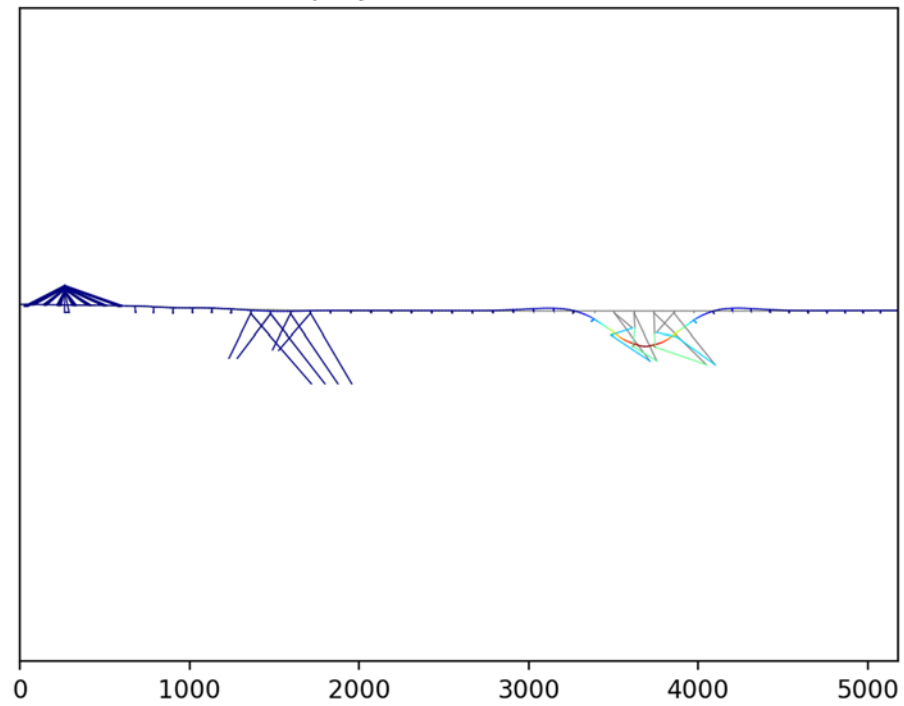
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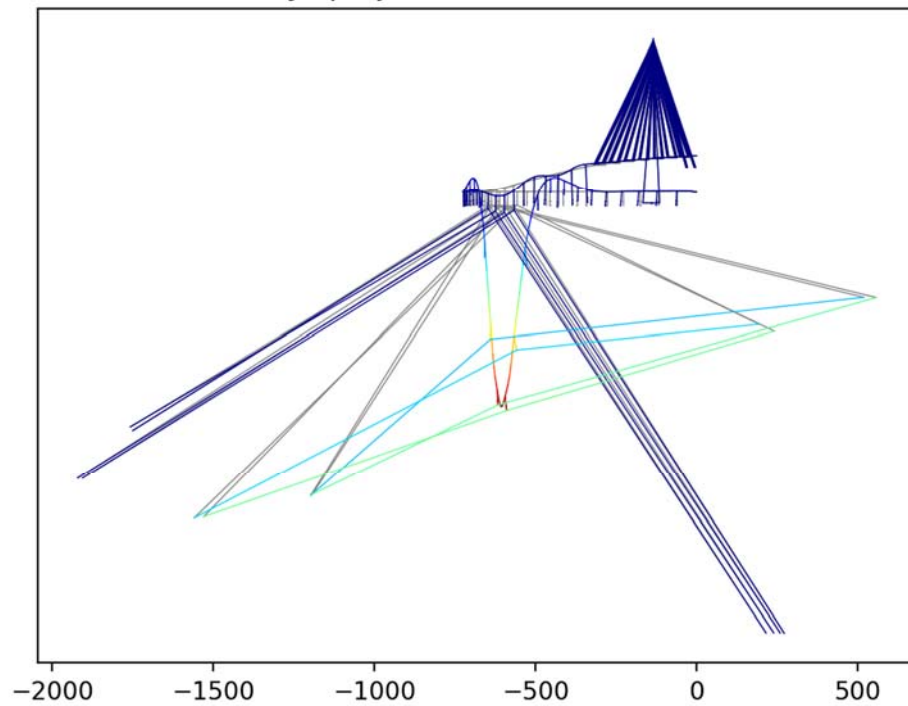
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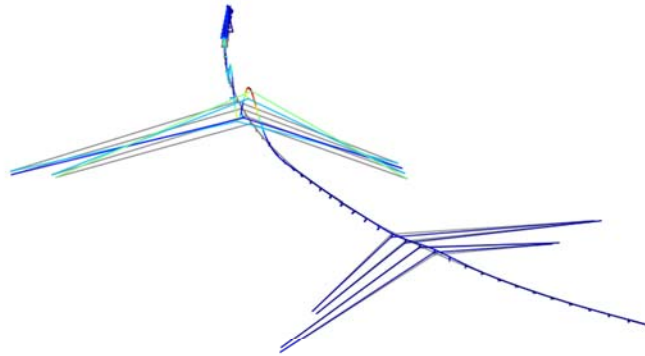
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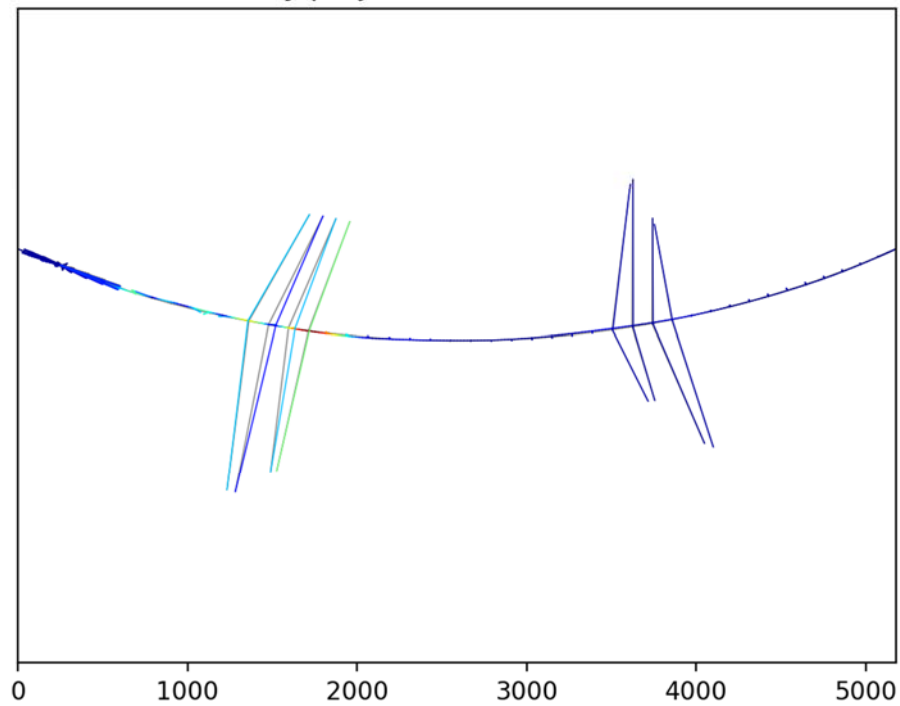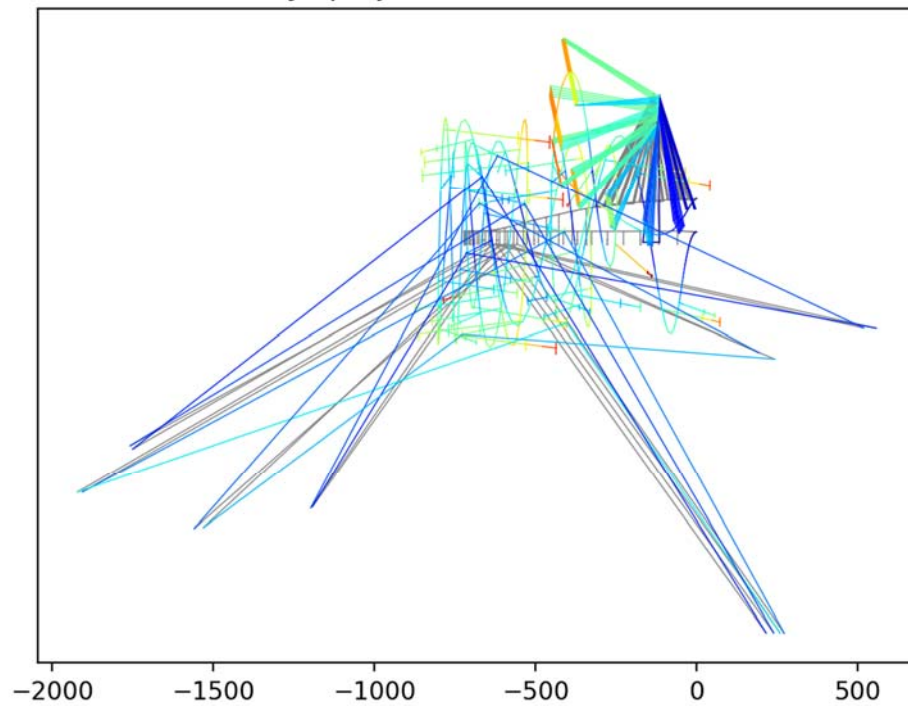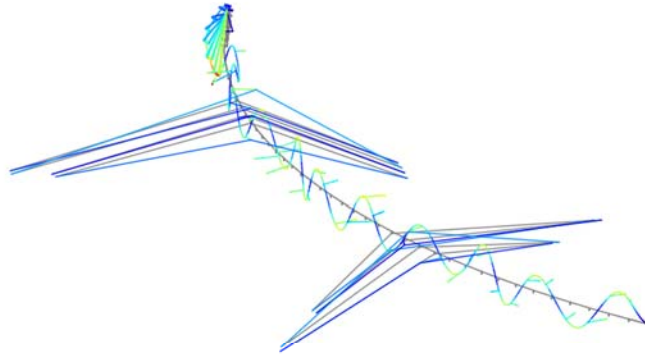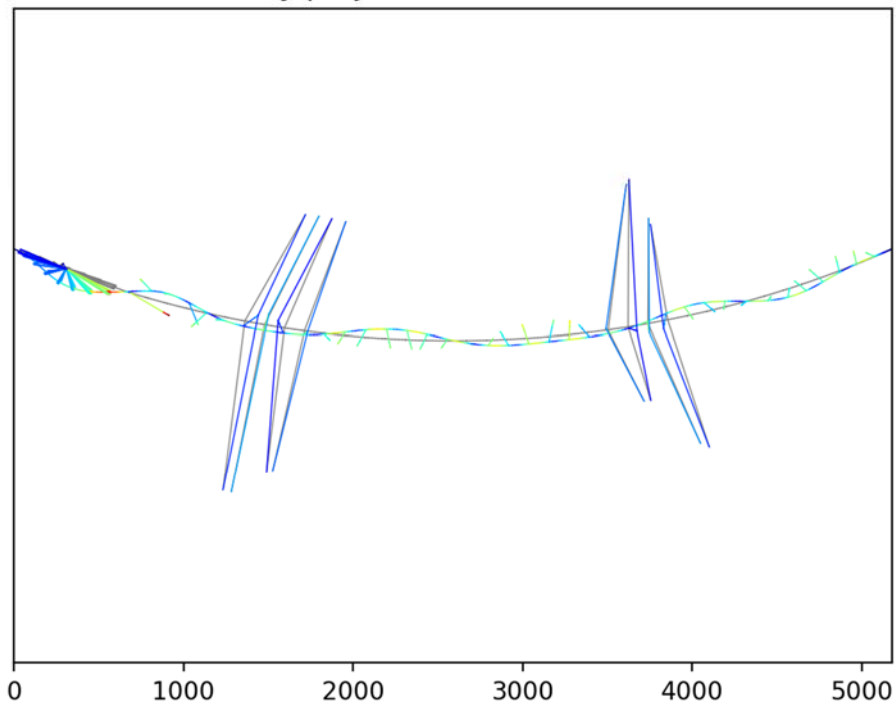
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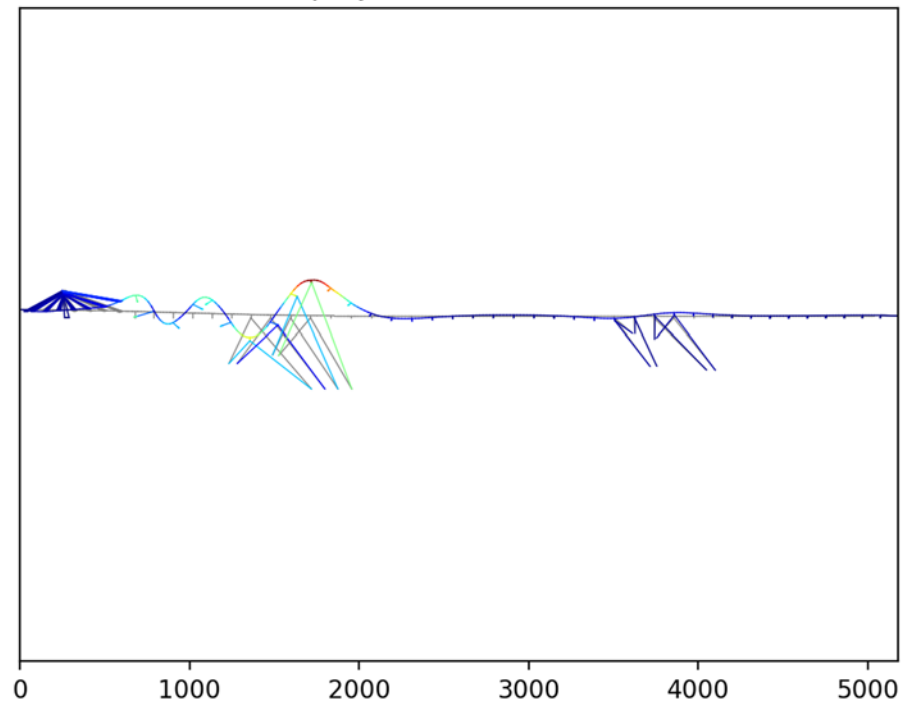
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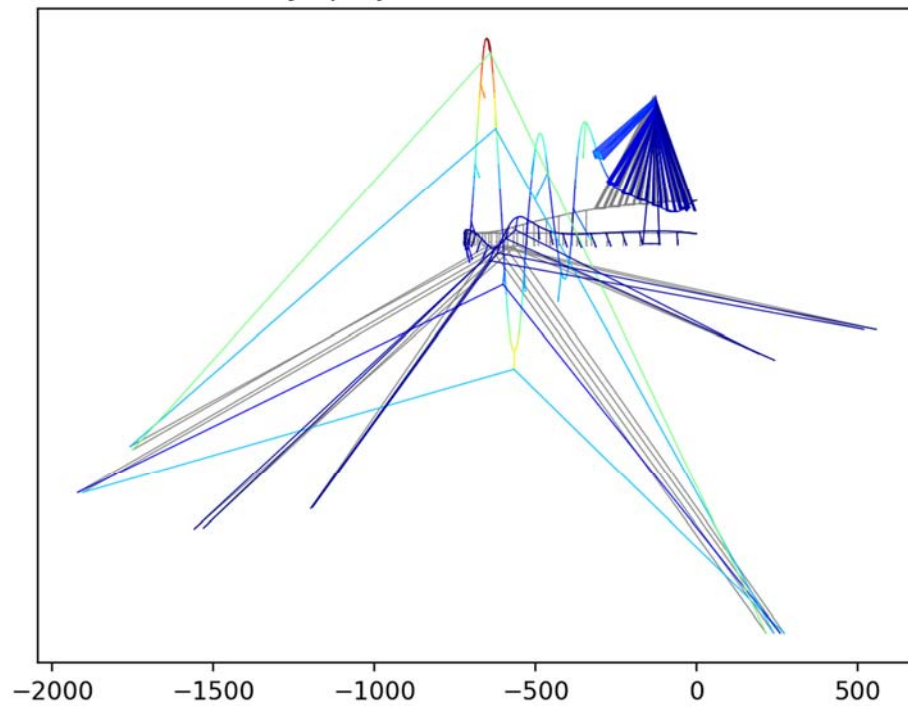
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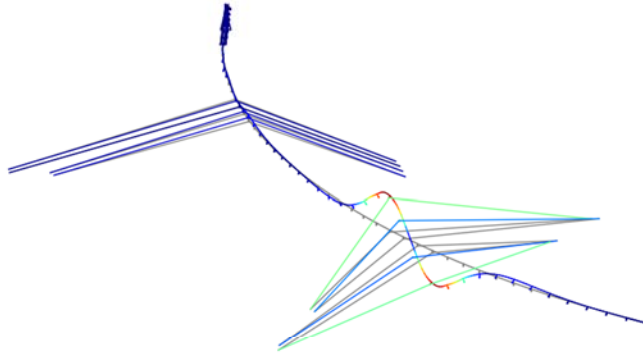
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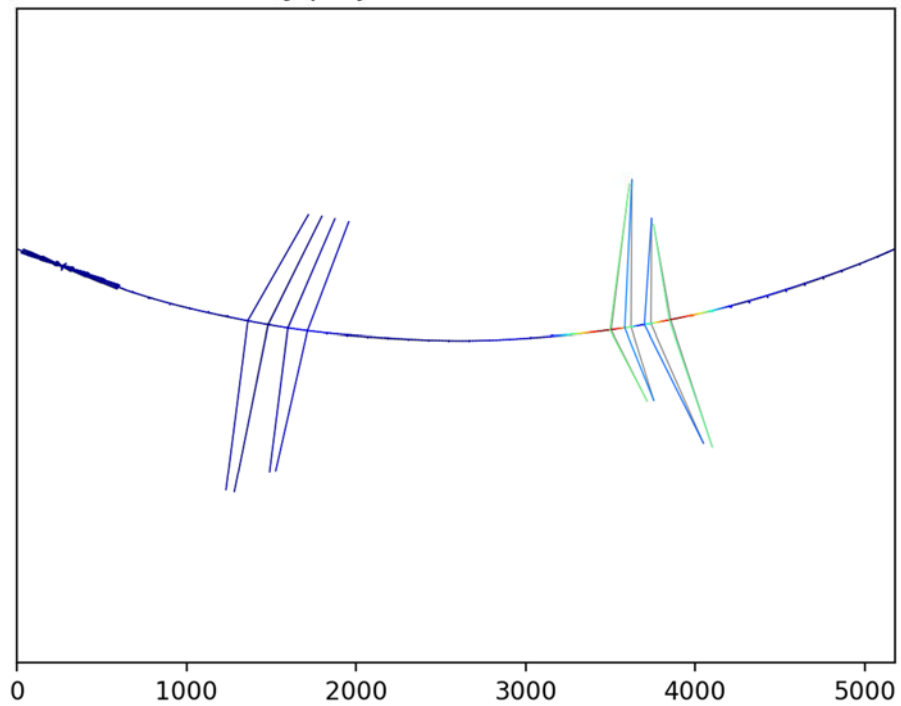
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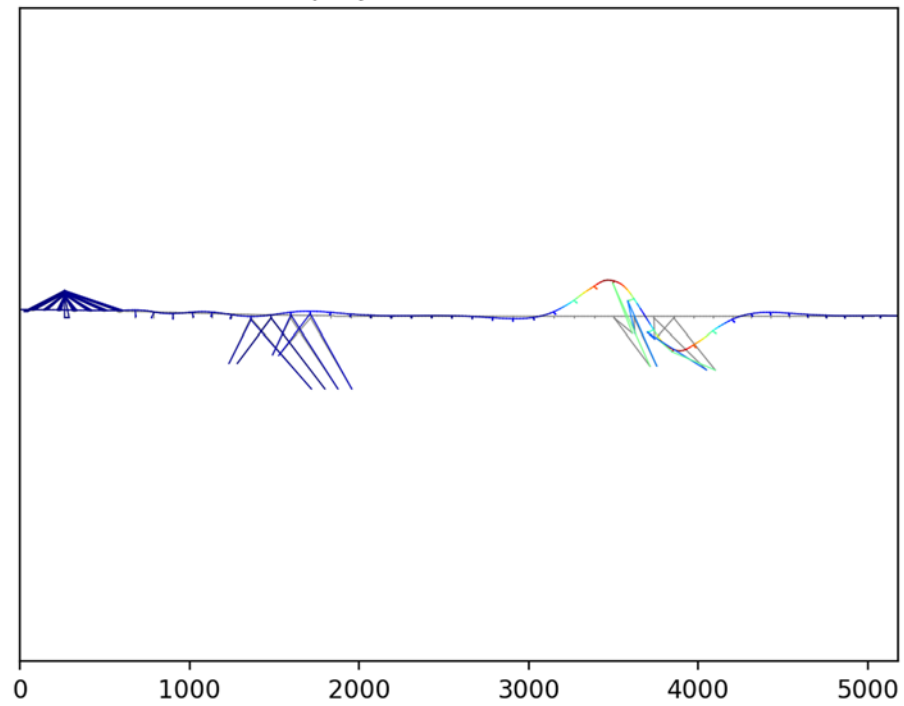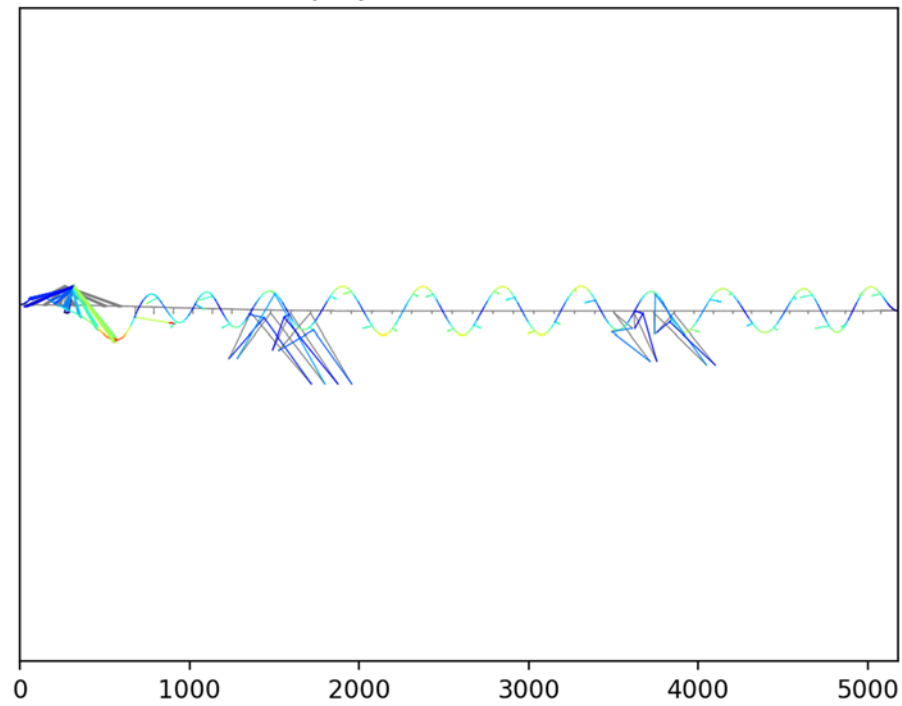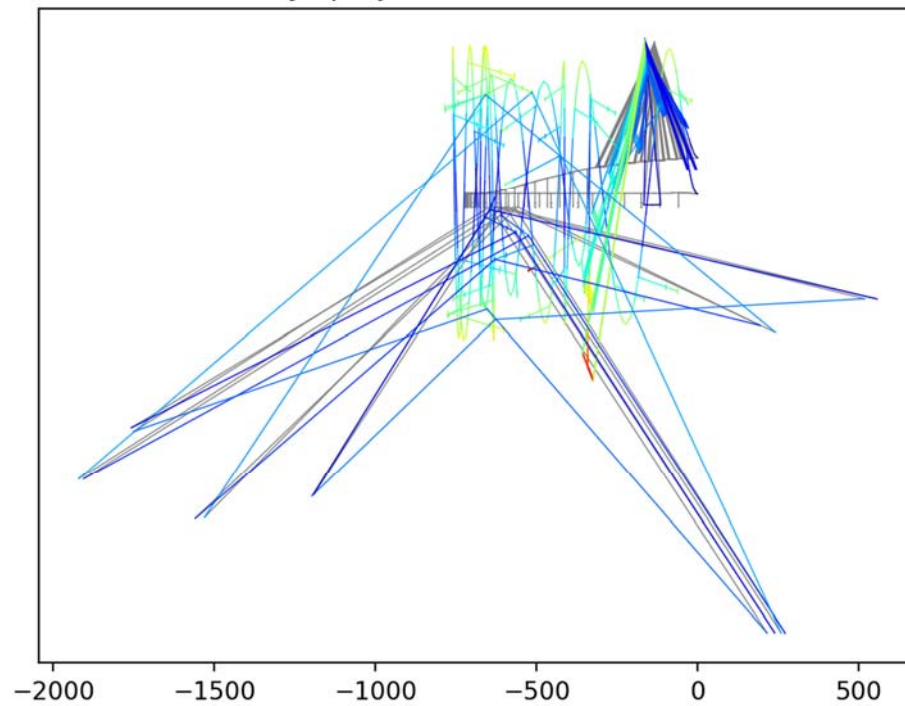

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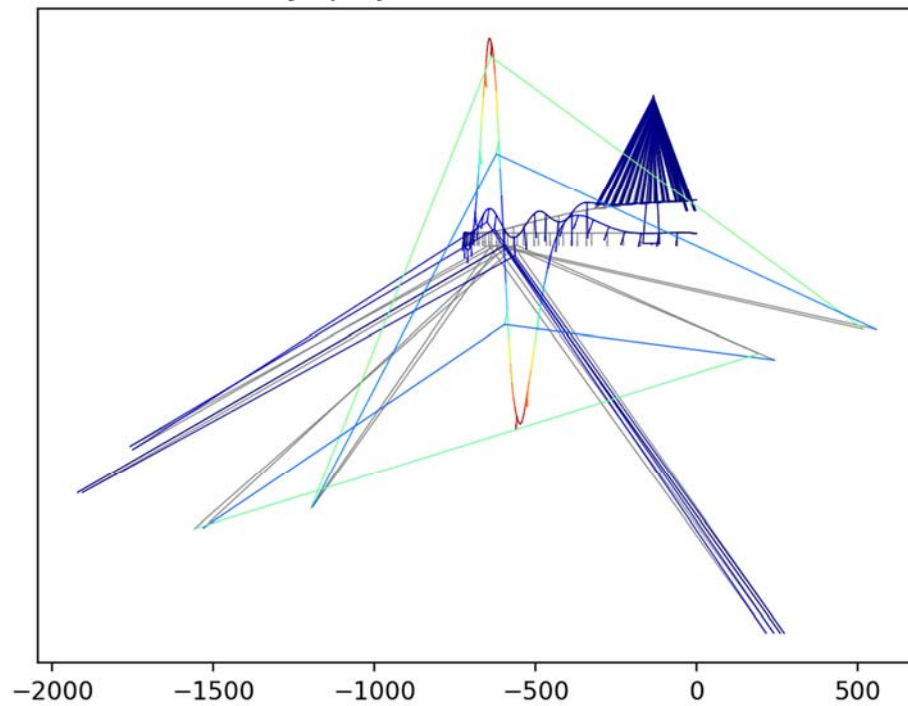
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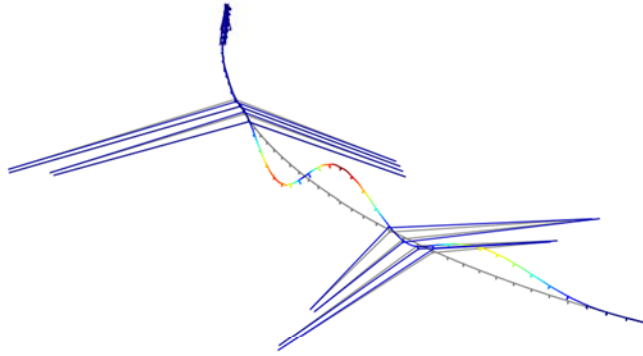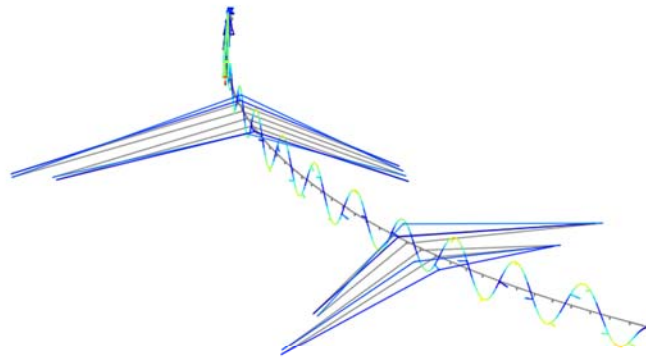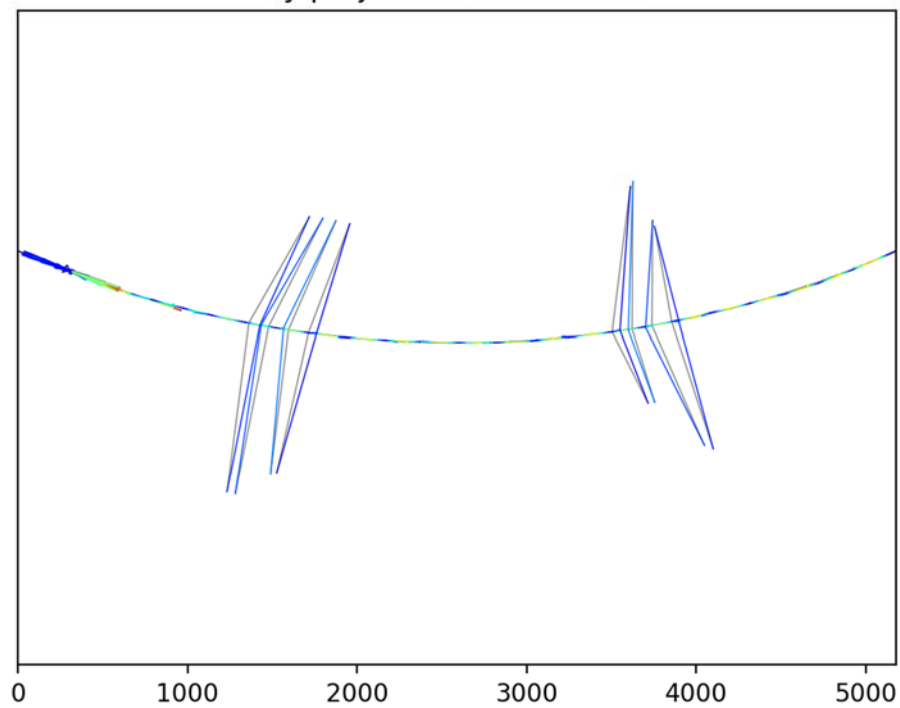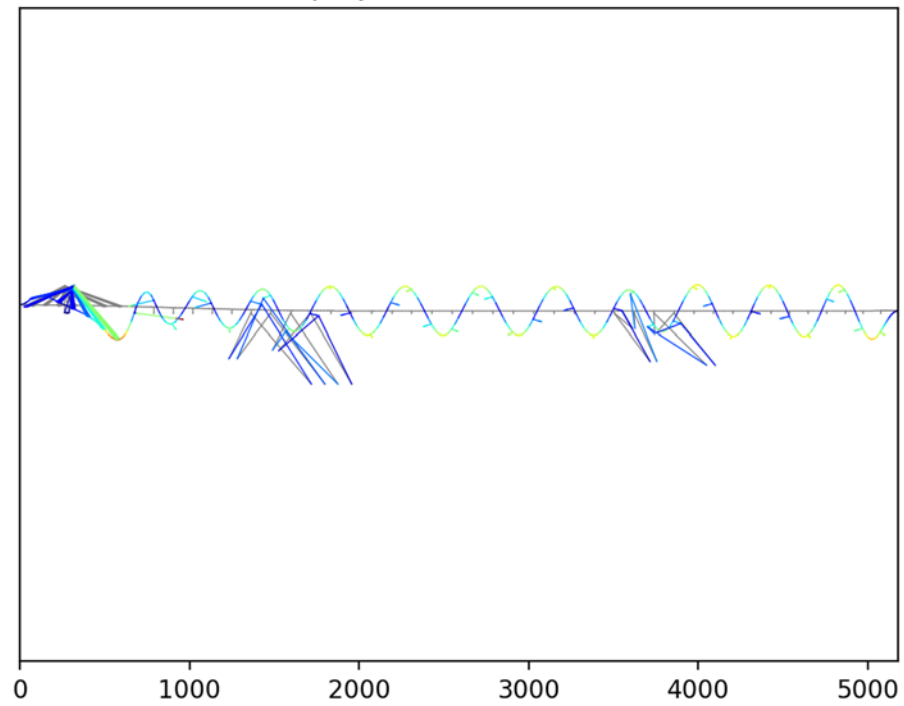

xy projection for mode 22
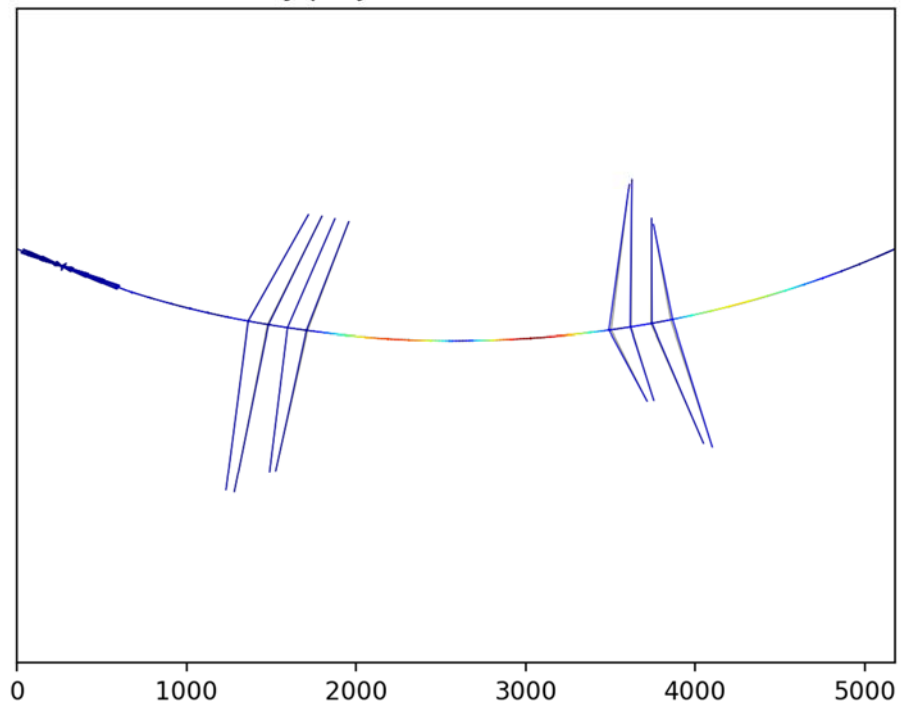
xz projection for mode 22
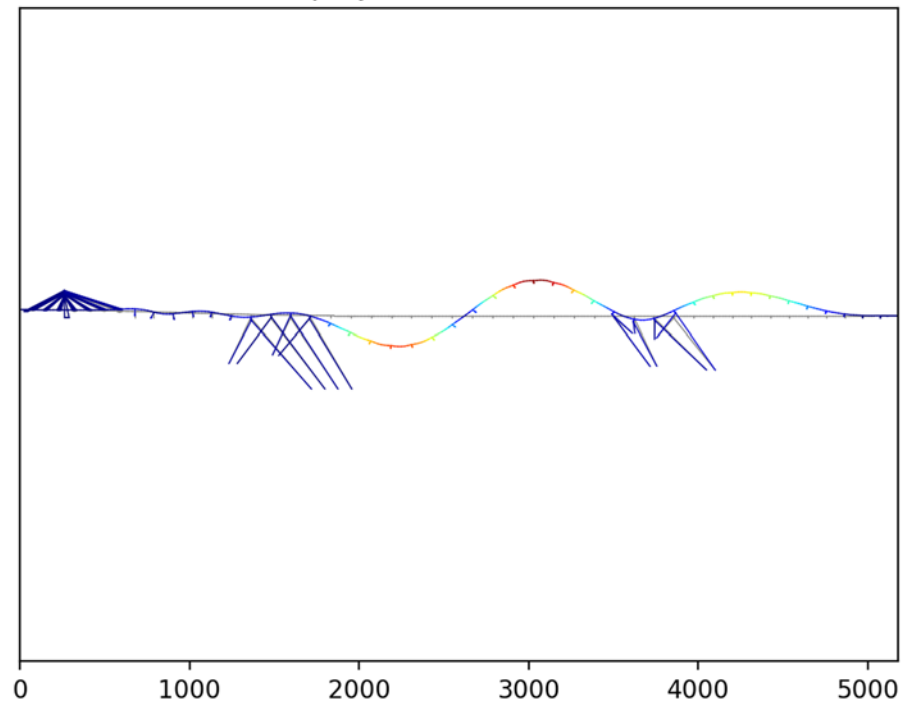
yz projection for mode 22
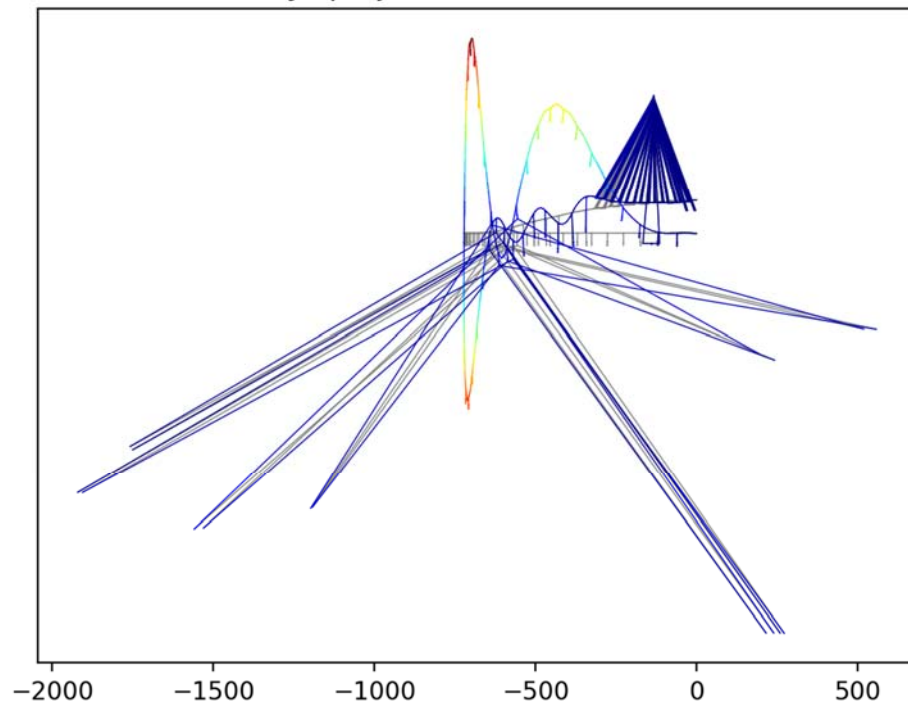
iso projection for mode 23
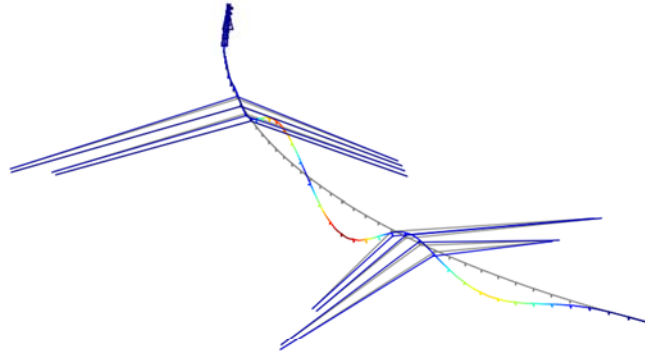
xy projection for mode 23
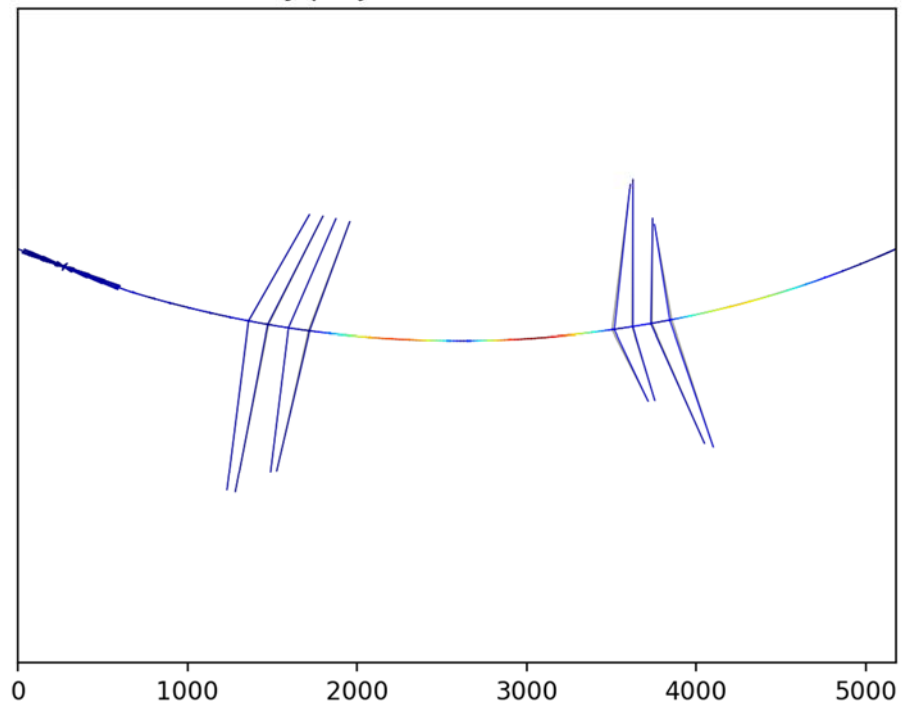
xz projection for mode 23
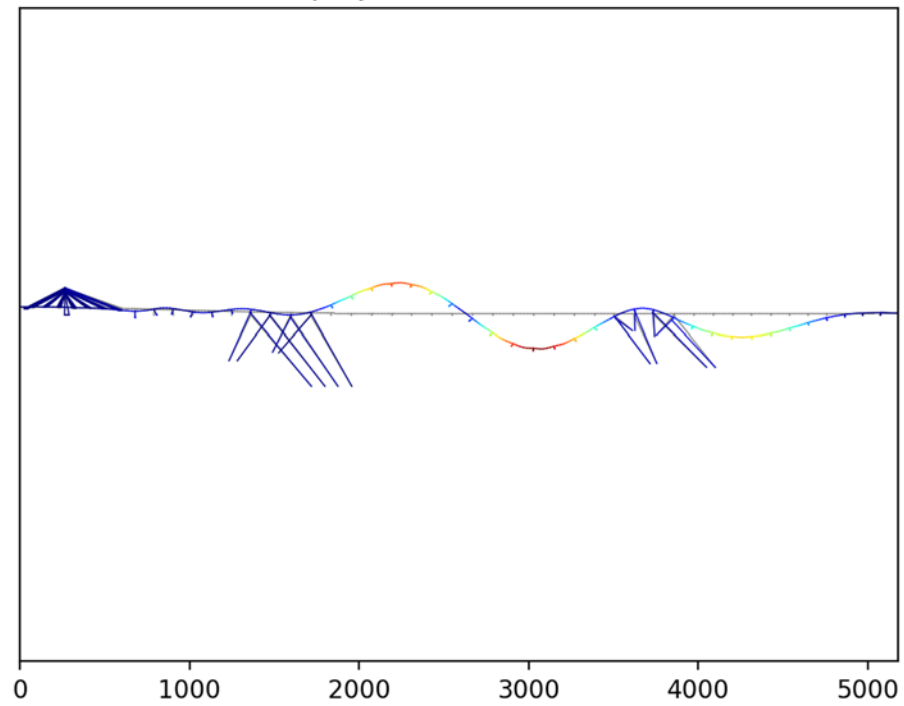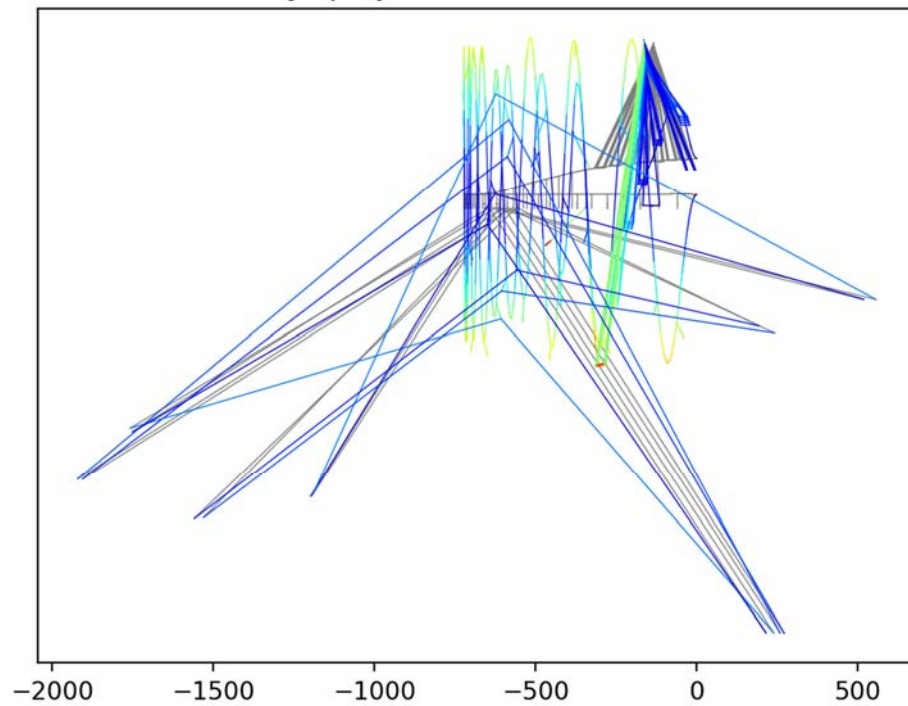

yz projection for mode 23
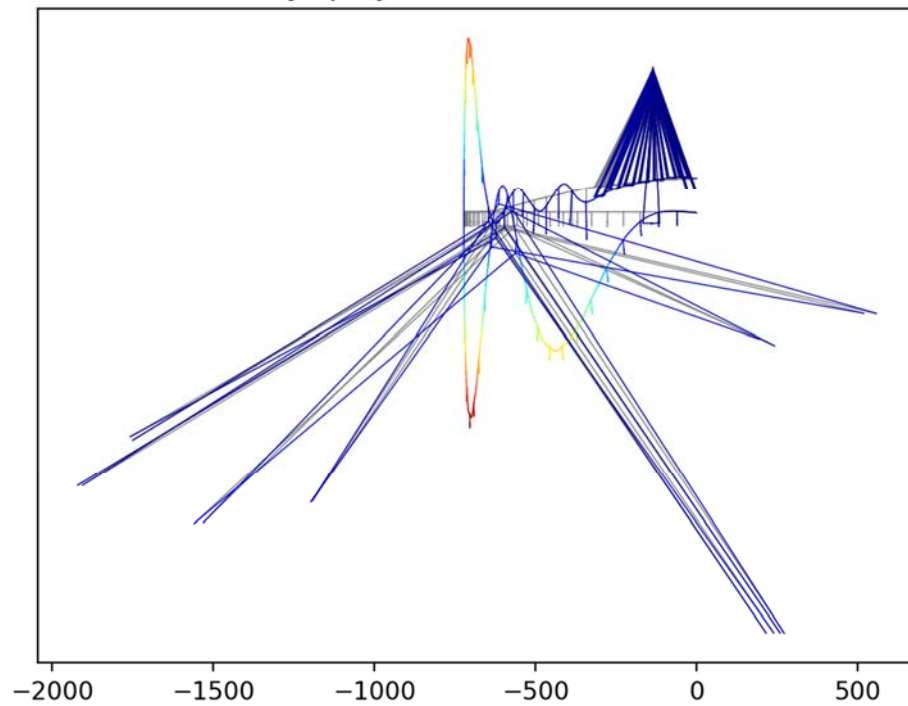
iso projection for mode 24
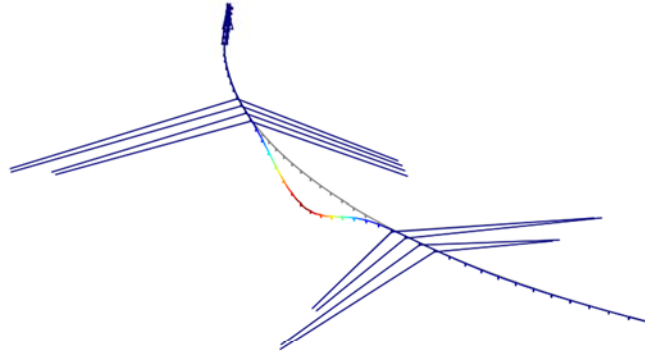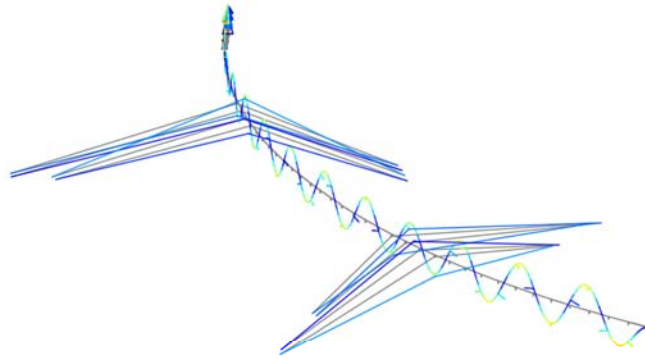

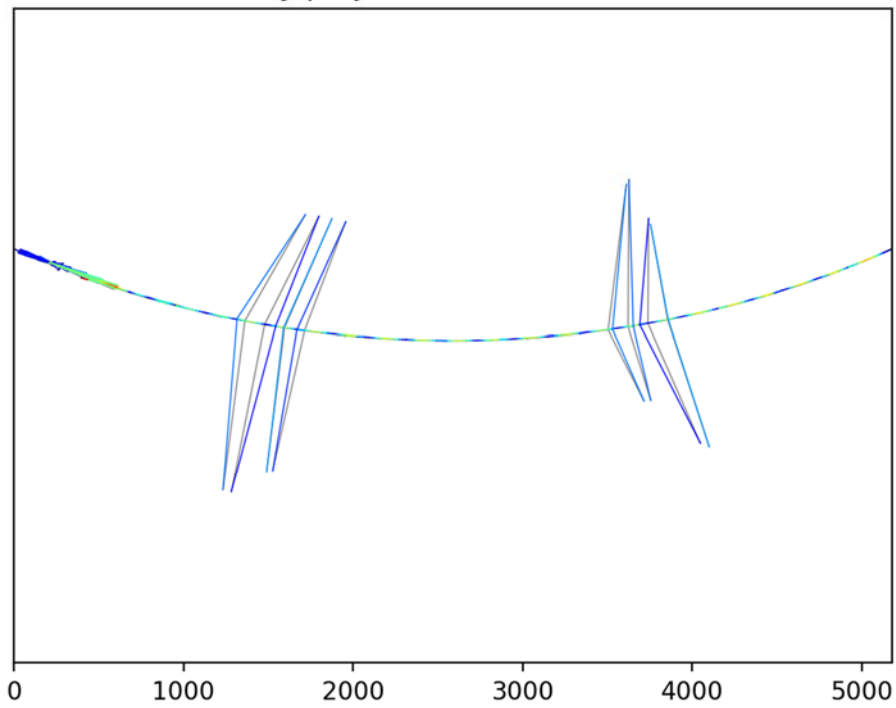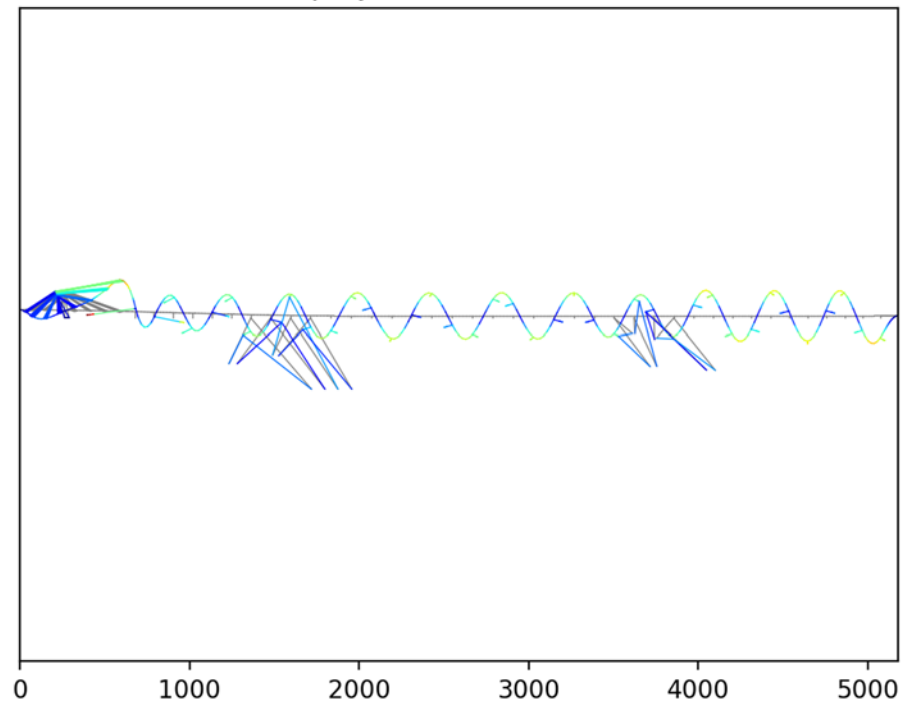xy projection for mode 24
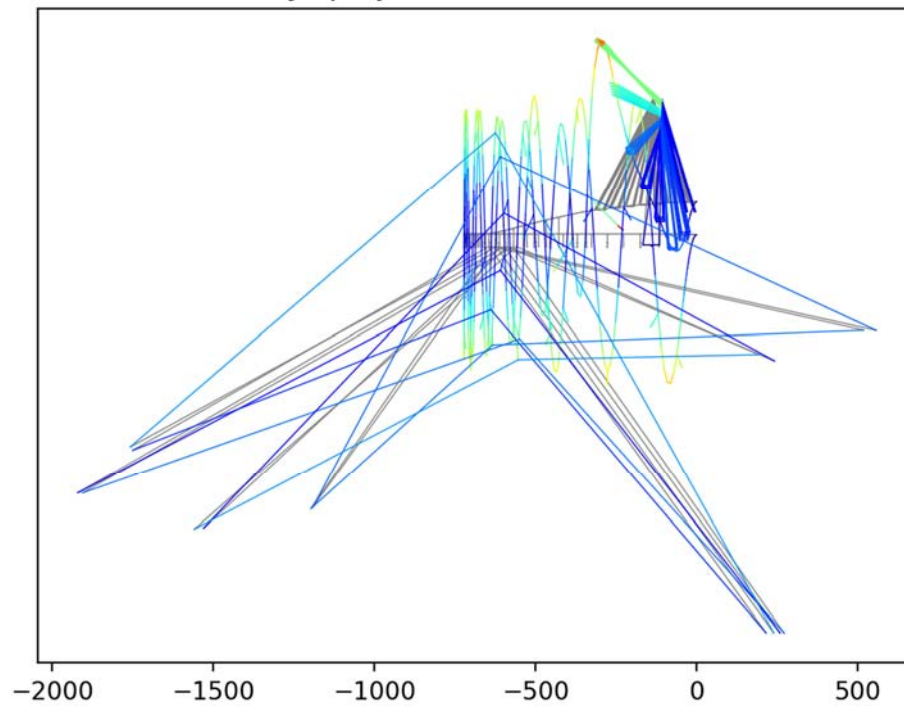
xz projection for mode 24

yz projection for mode 24

iso projection for mode 25
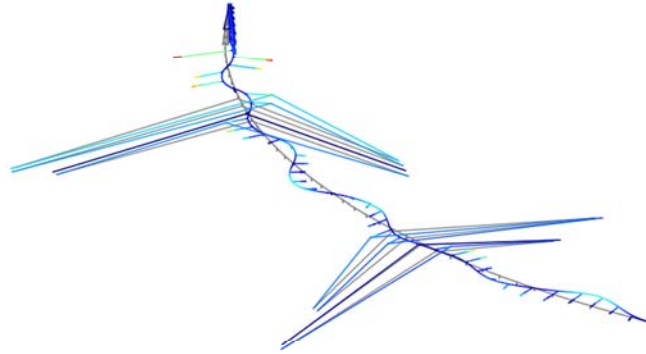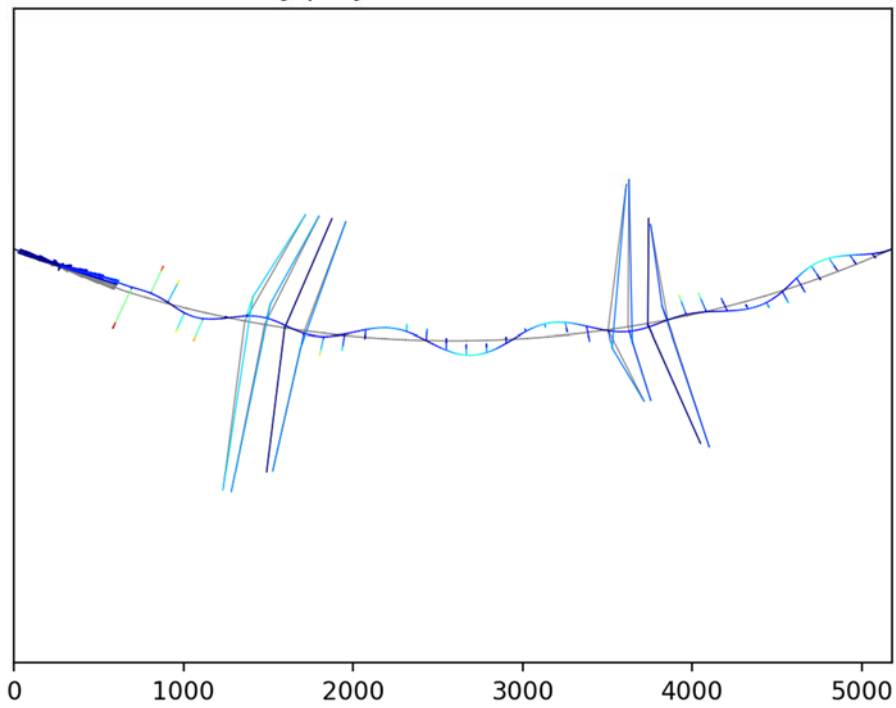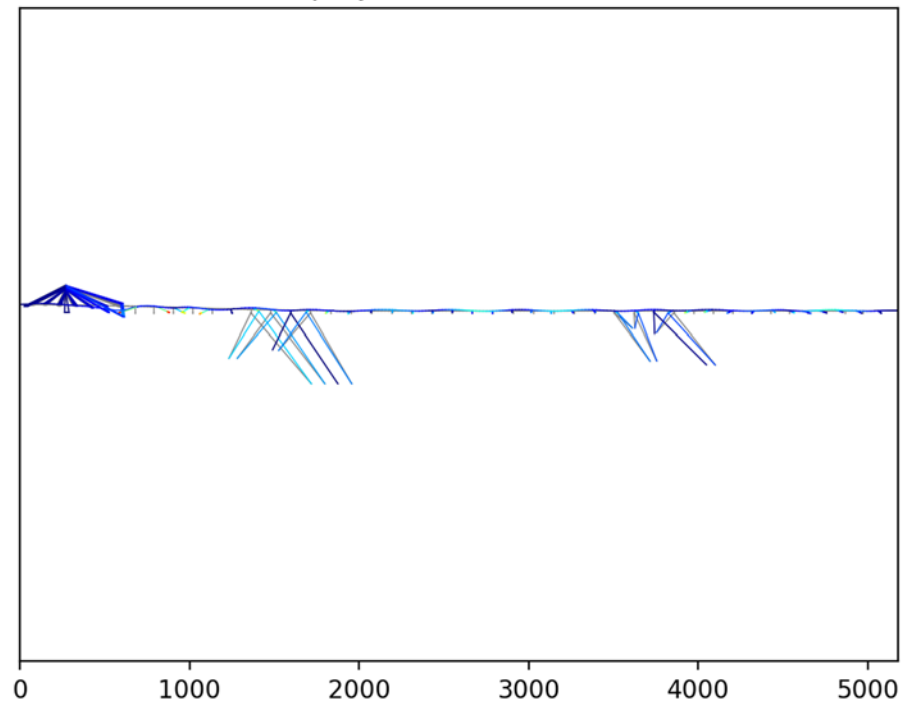

xy projection for mode 25

xz projection for mode 25

yz projection for mode 25

iso projection for mode 26
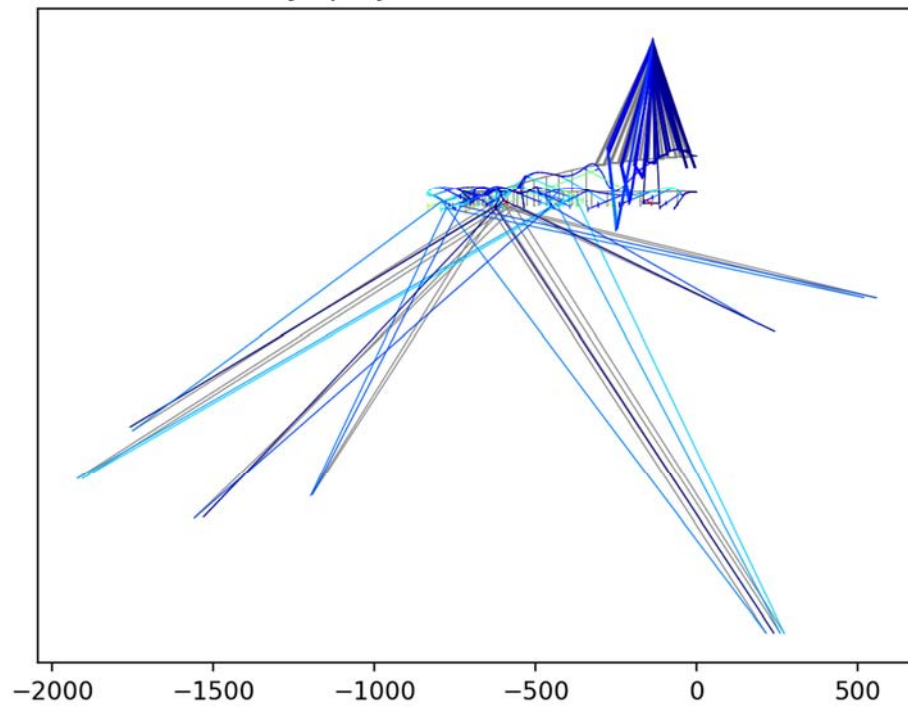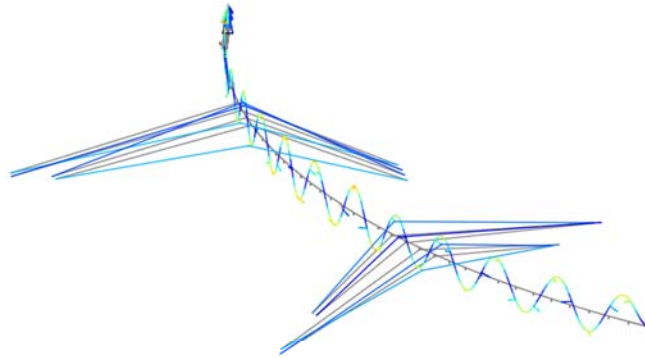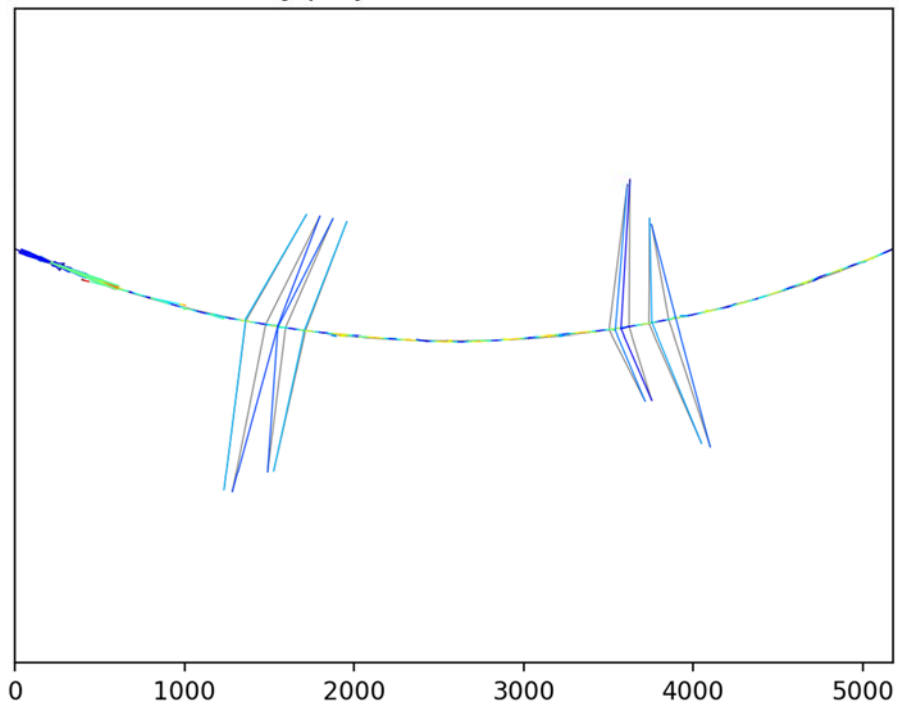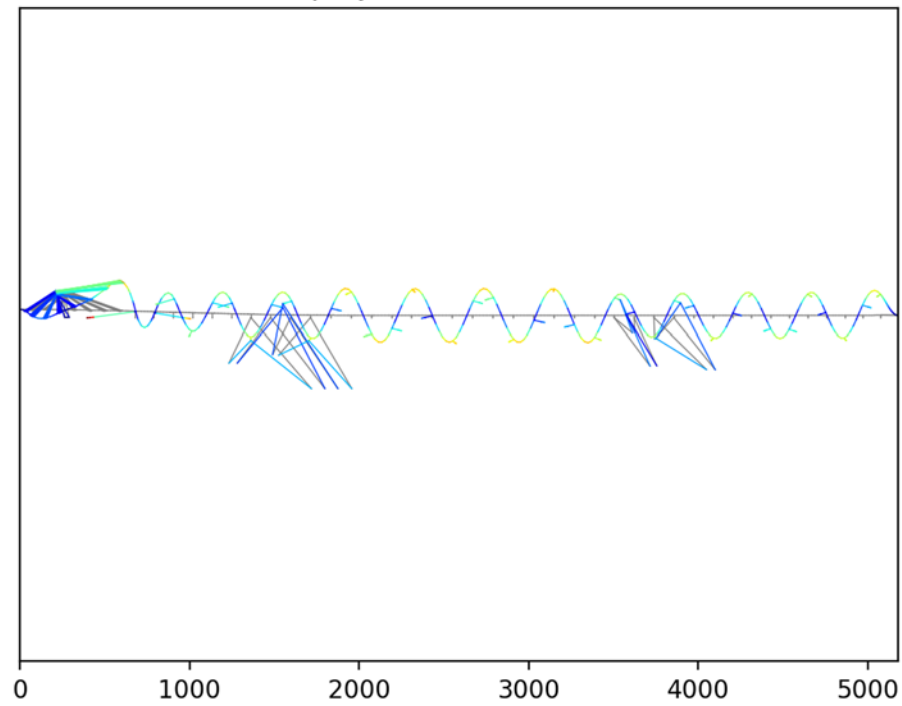

xy projection for mode 26

xz projection for mode 26

yz projection for mode 26

iso projection for mode 27
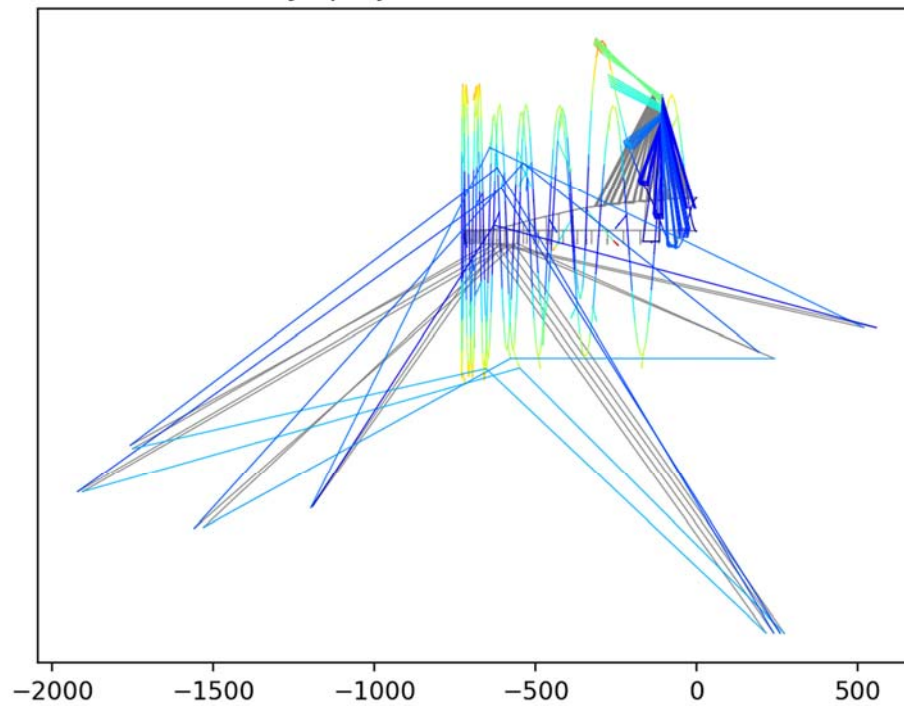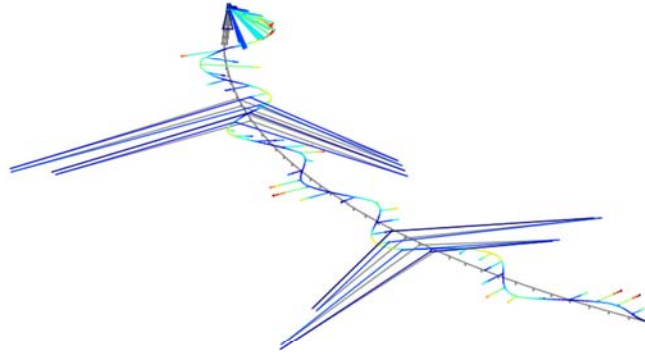

xy projection for mode 27

xz projection for mode 27

yz projection for mode 27

iso projection for mode 28

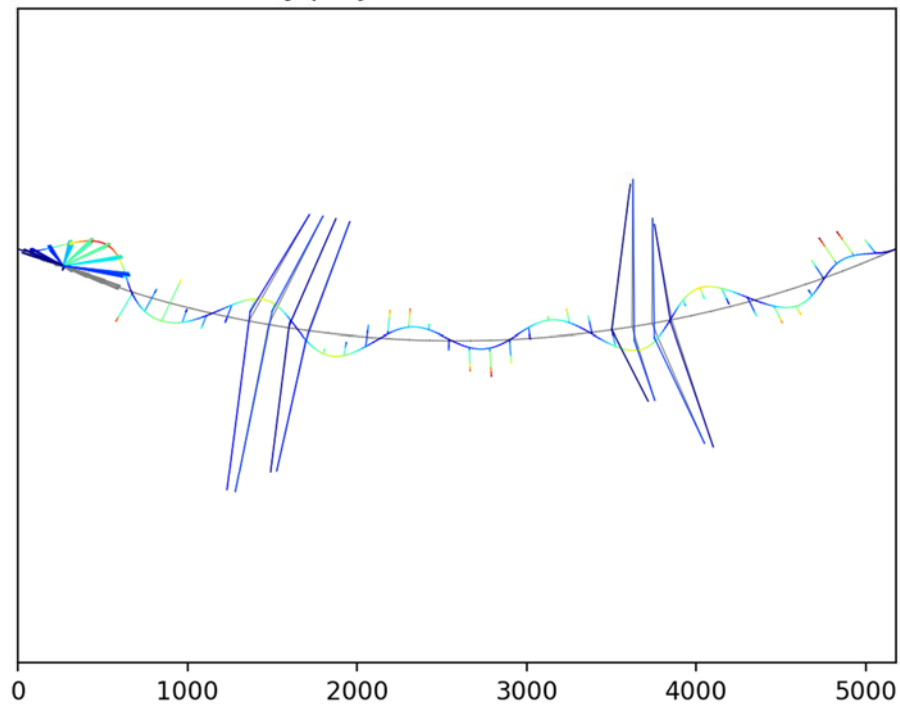xy projection for mode 28

xz projection for mode 28
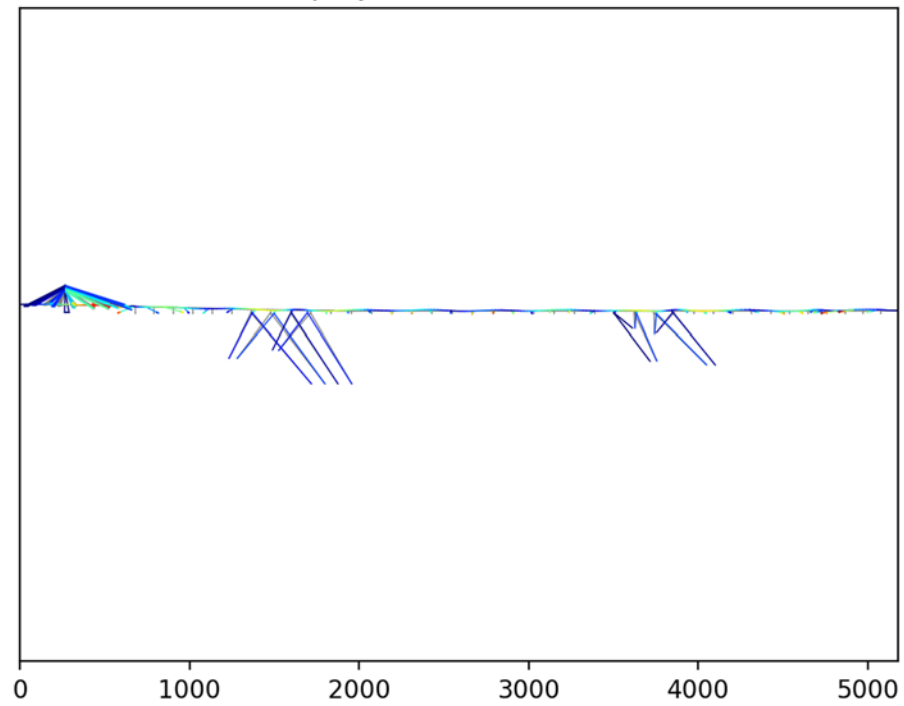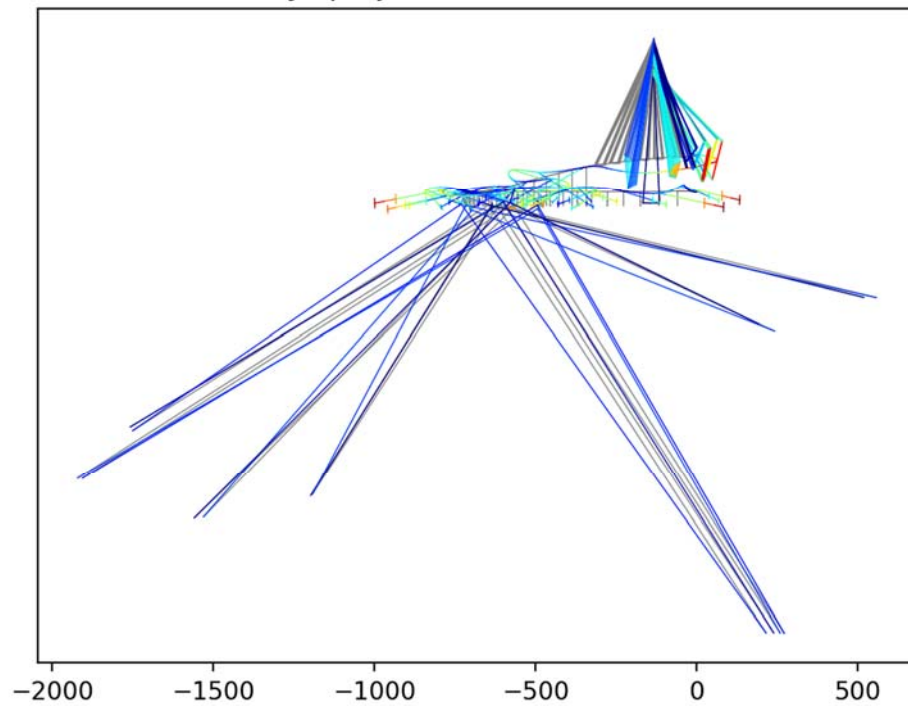

yz projection for mode 28

iso projection for mode 29
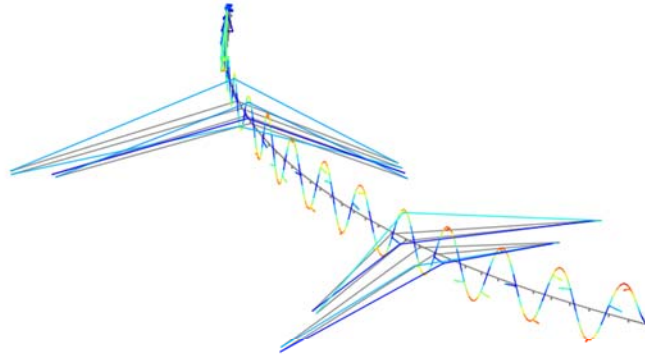

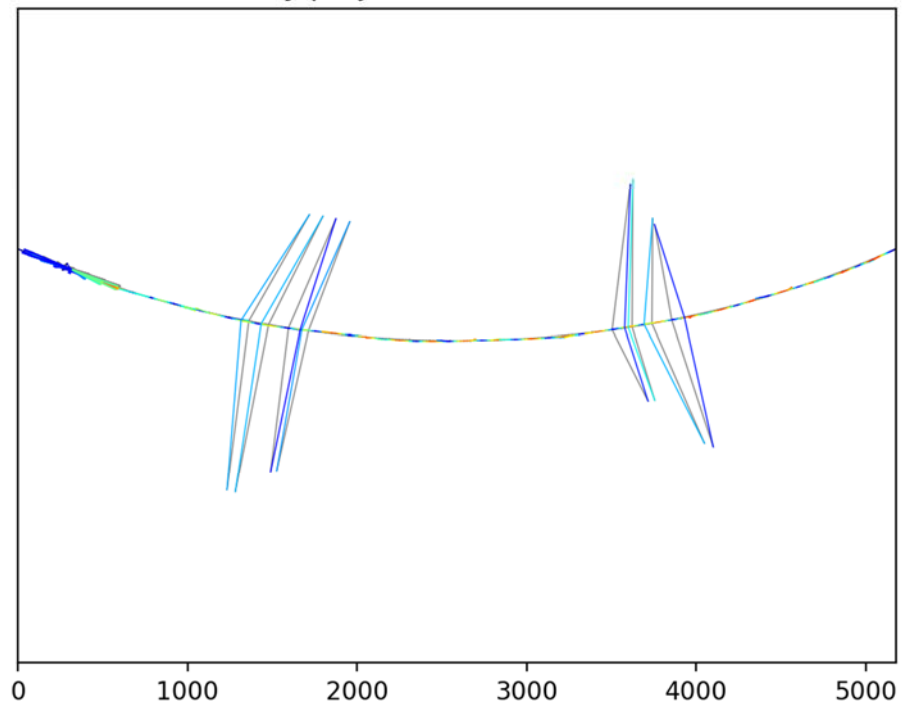xy projection for mode 29

xz projection for mode 29
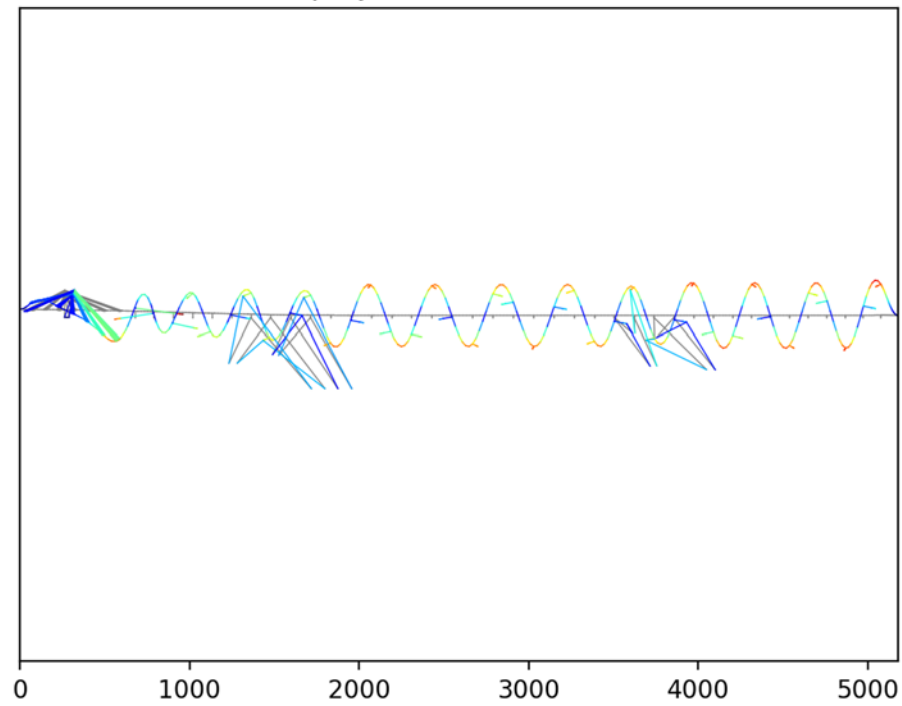

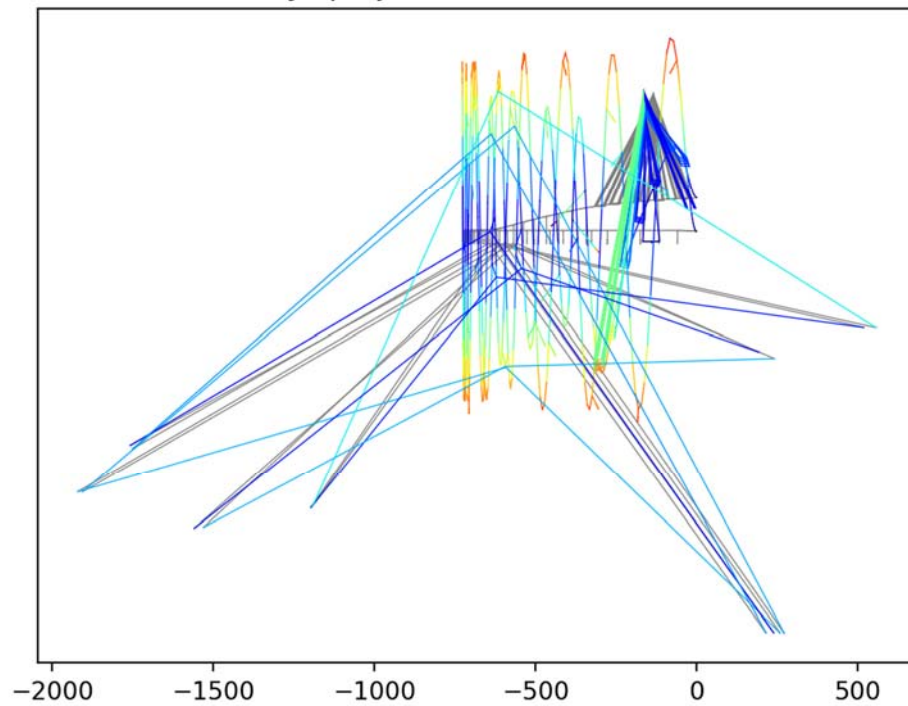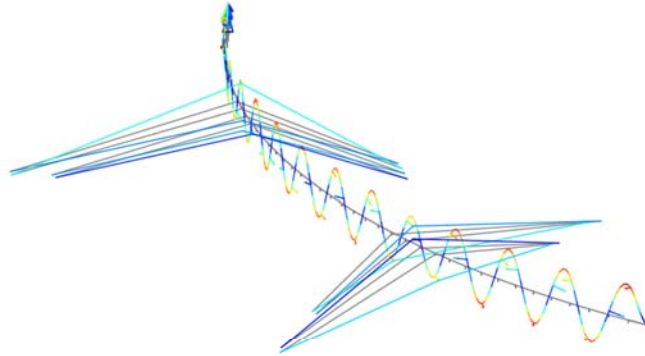## yz projection for mode 29

iso projection for mode 30

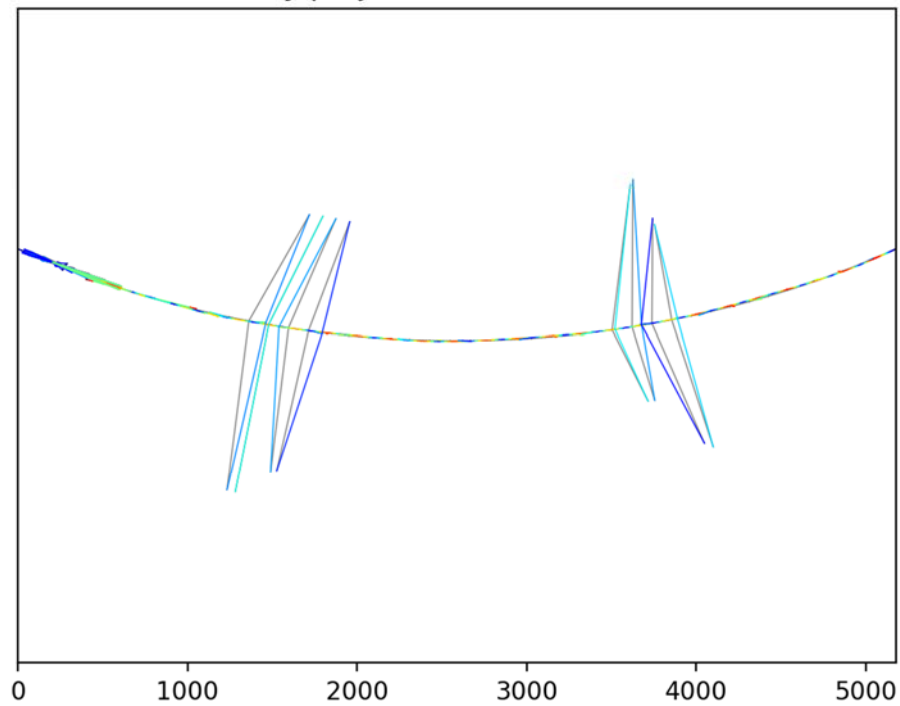xy projection for mode 30

xz projection for mode 30

yz projection for mode 30

iso projection for mode 31

xy projection for mode 31

xz projection for mode 31
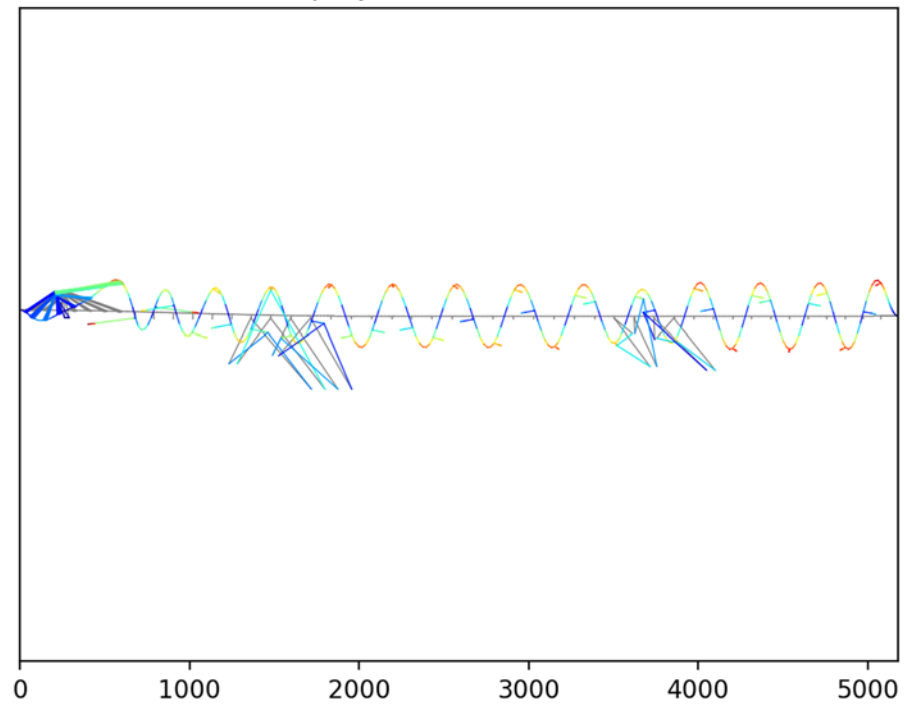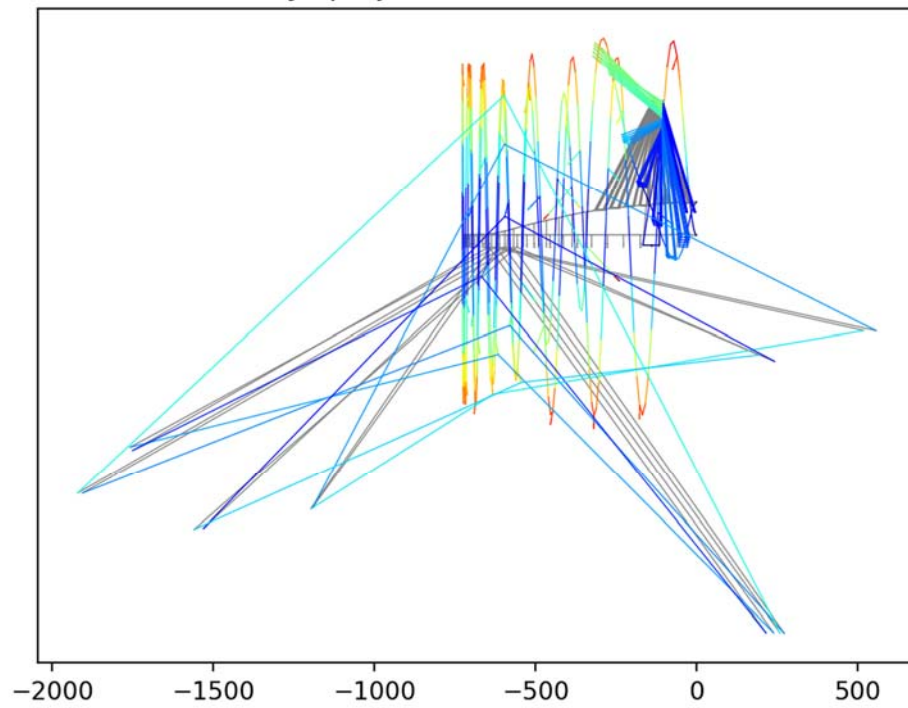

yz projection for mode 31

iso projection for mode 32
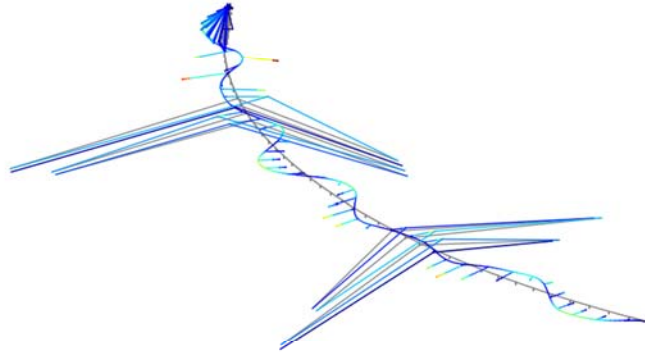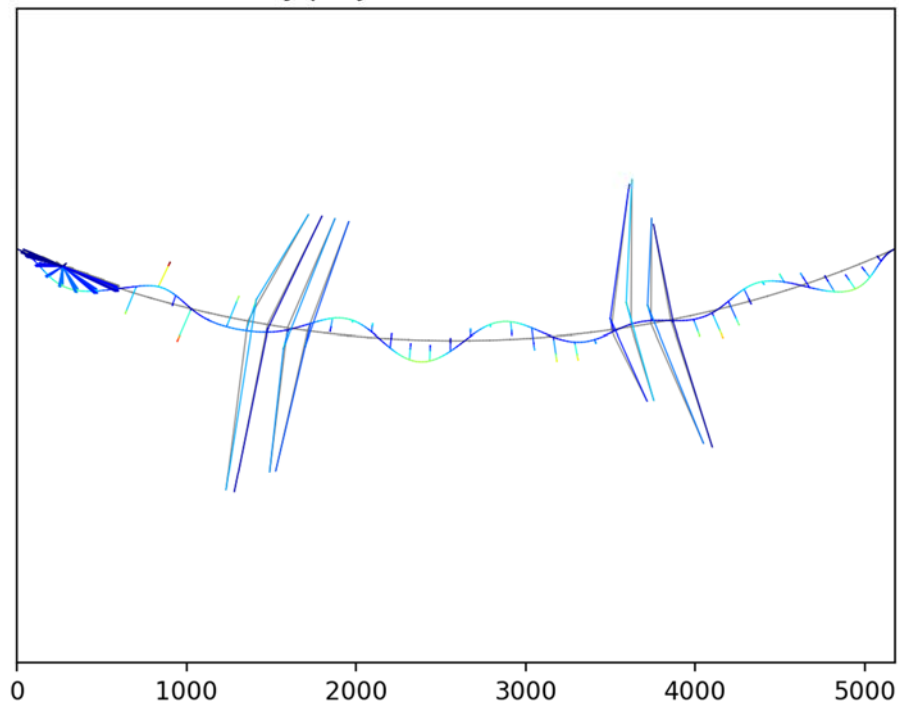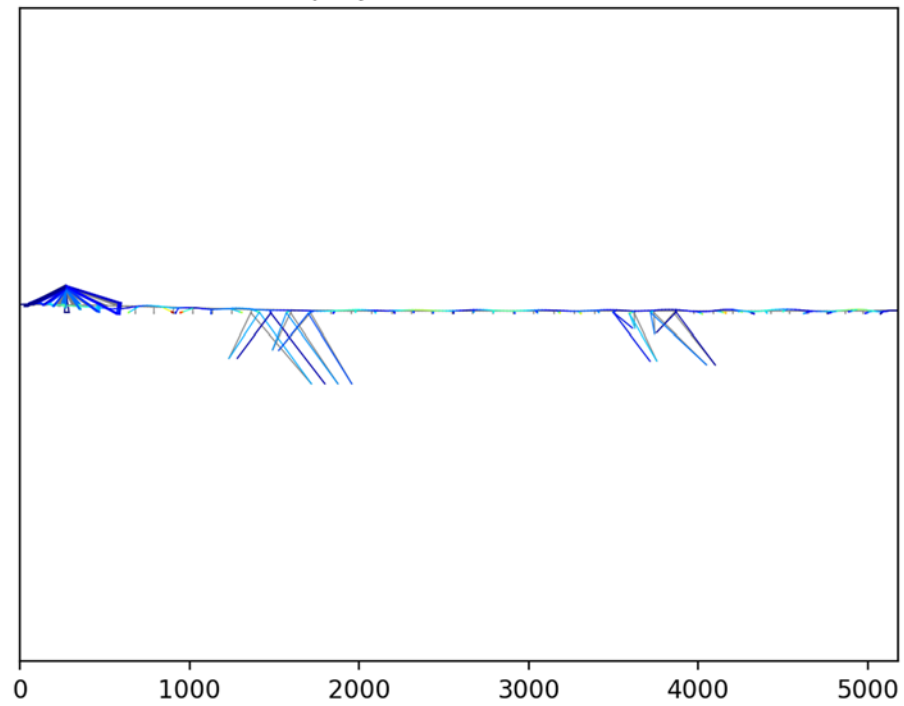

xy projection for mode 32

xz projection for mode 32

yz projection for mode 32

iso projection for mode 33

xy projection for mode 33

xz projection for mode 33
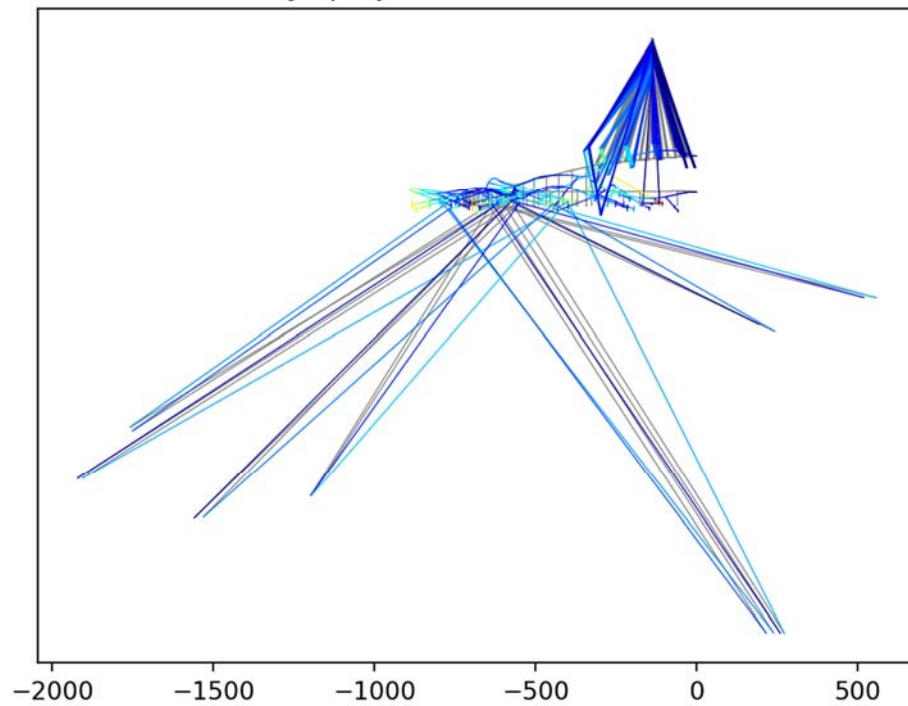

yz projection for mode 33

iso projection for mode 34
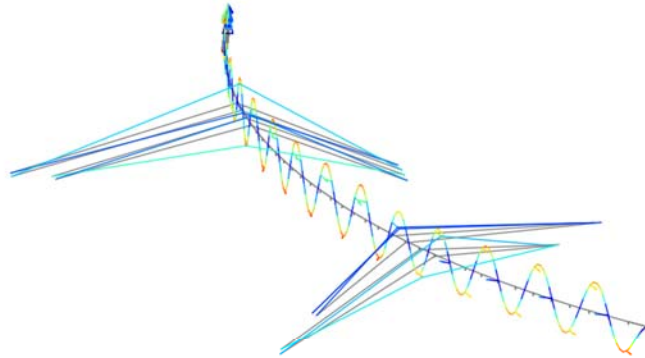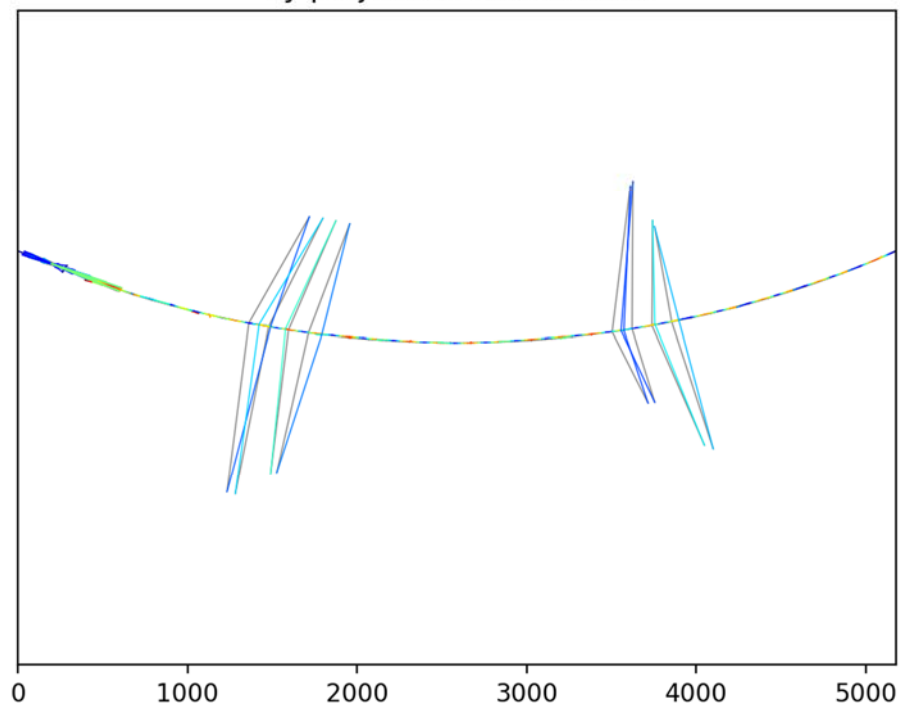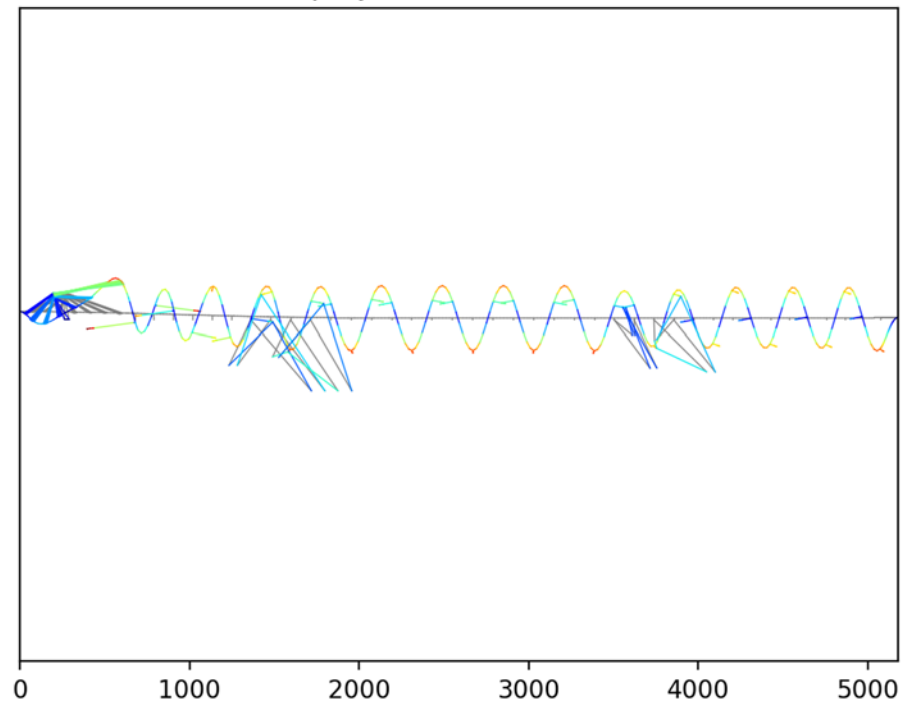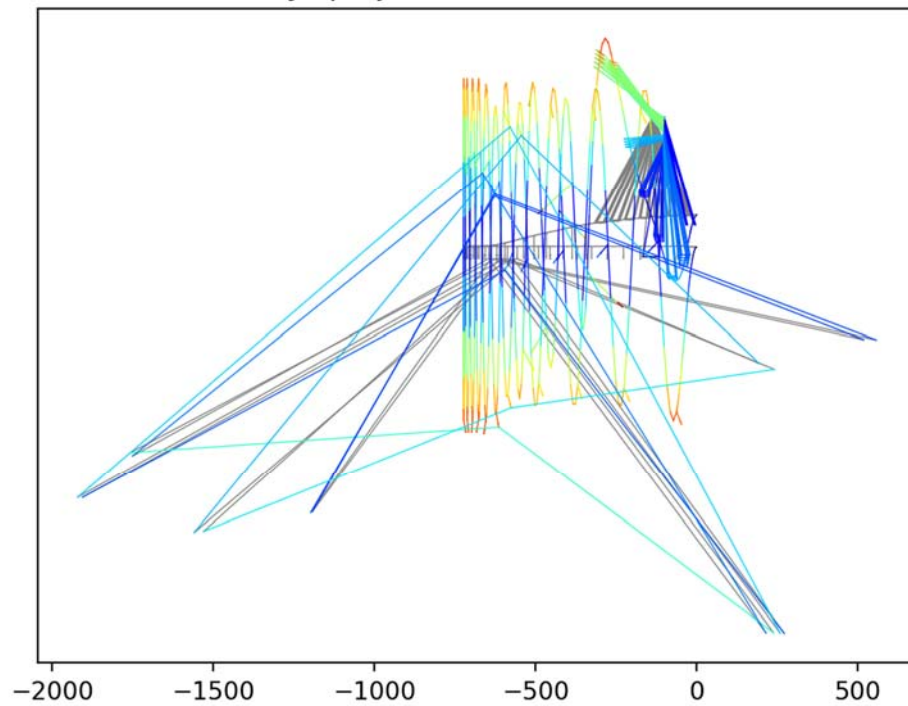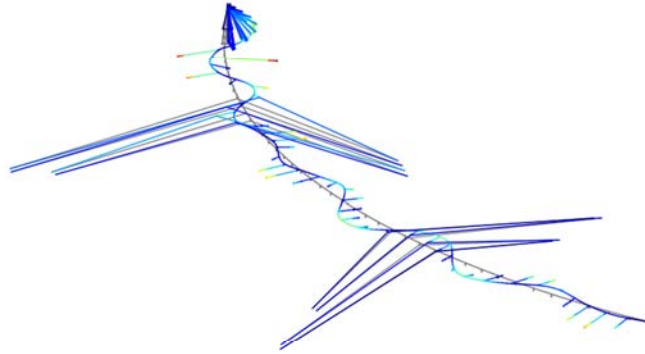

xy projection for mode 34
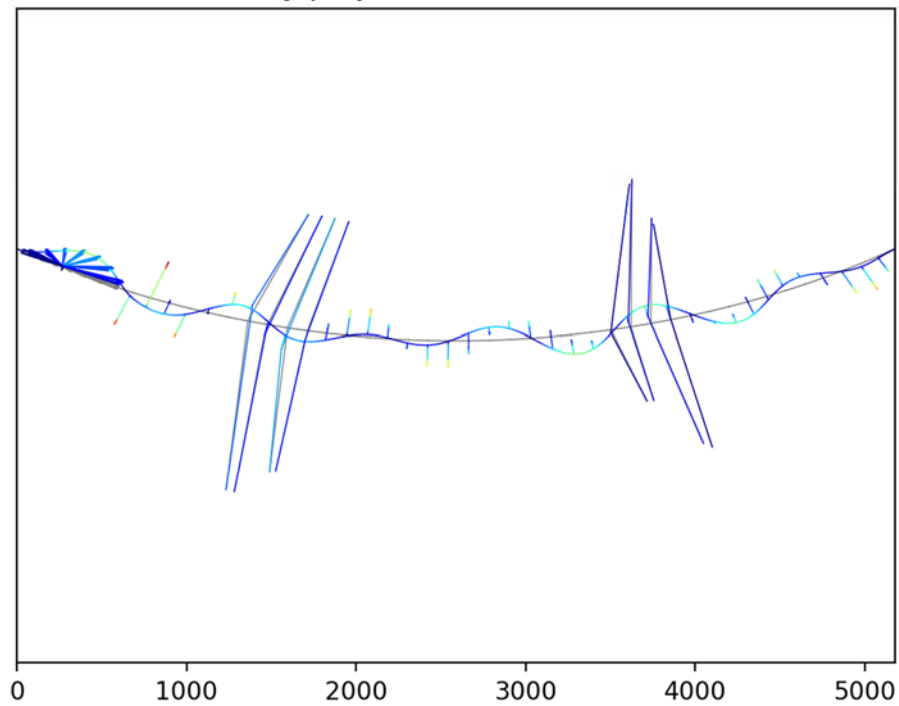
xz projection for mode 34
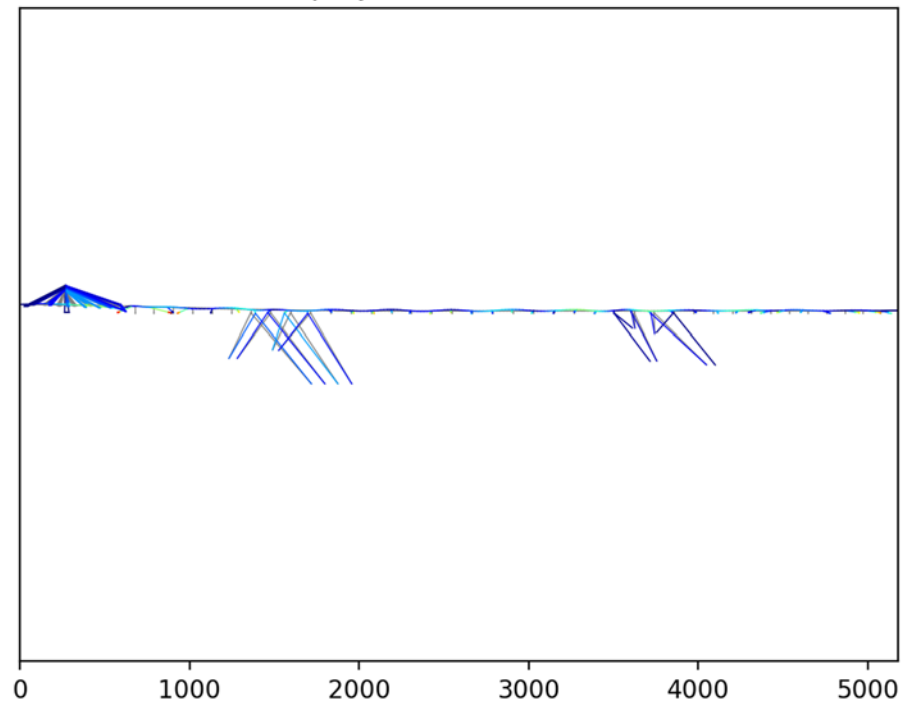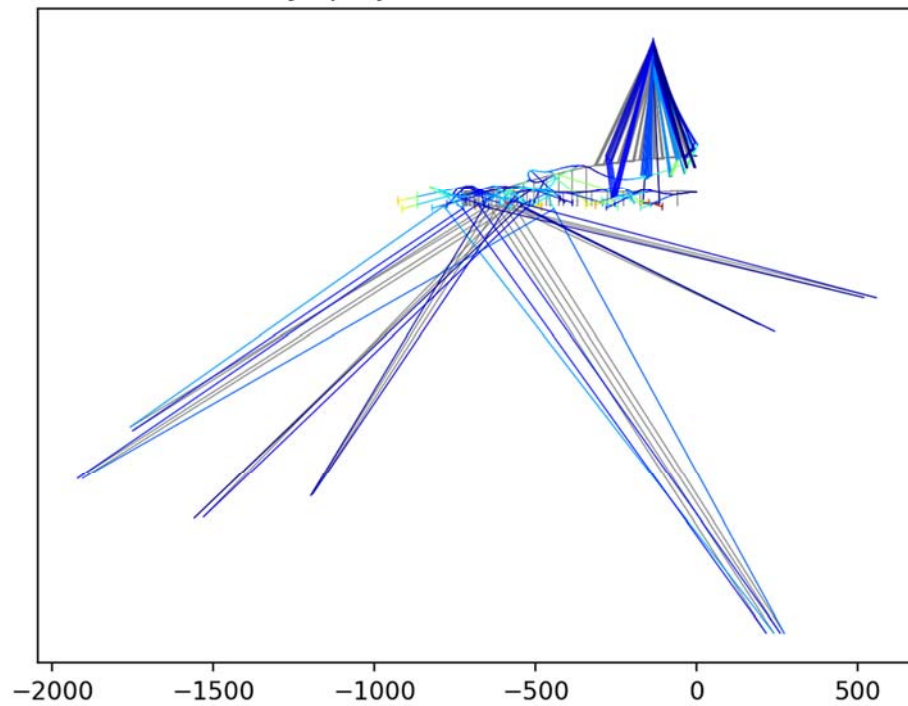

yz projection for mode 34

iso projection for mode 35
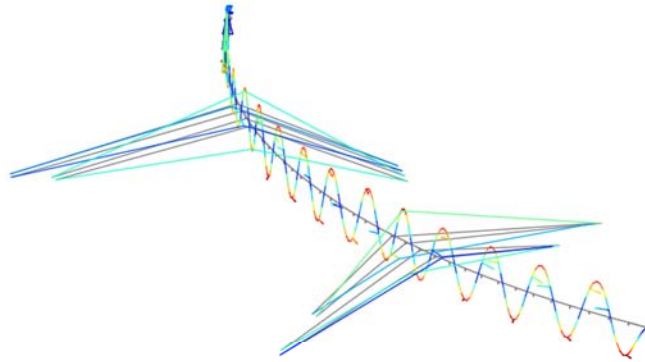

xy projection for mode 35

xz projection for mode 35

yz projection for mode 35

iso projection for mode 36

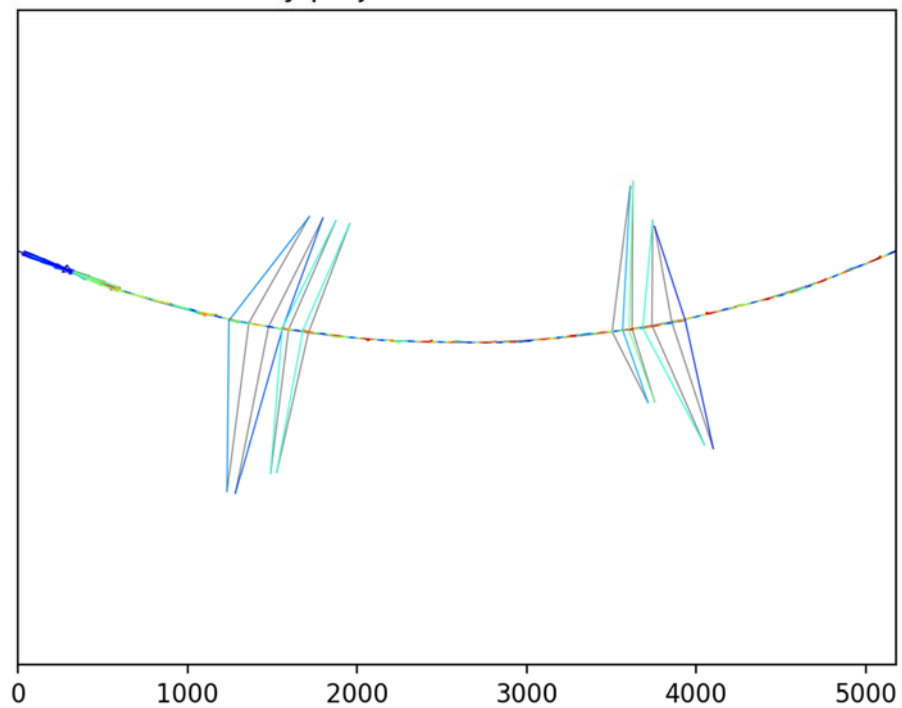xy projection for mode 36

xz projection for mode 36
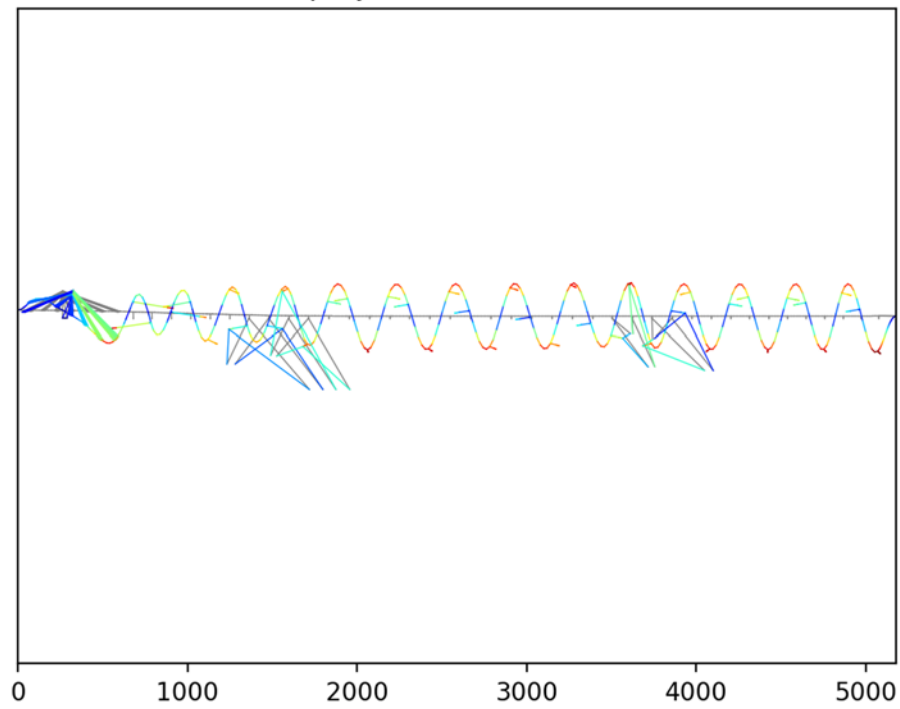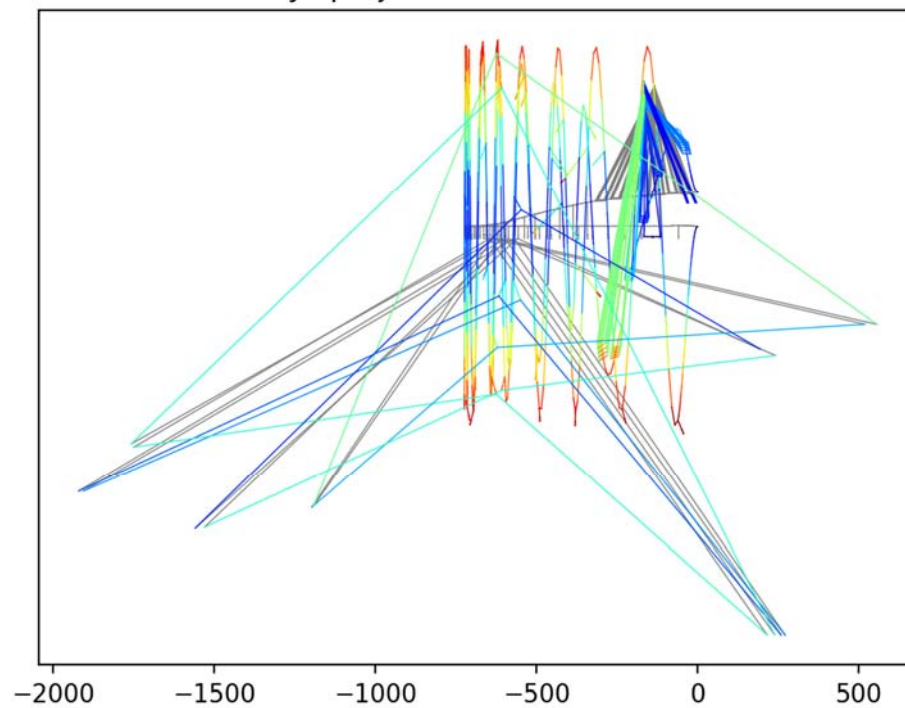

yz projection for mode 36

iso projection for mode 37
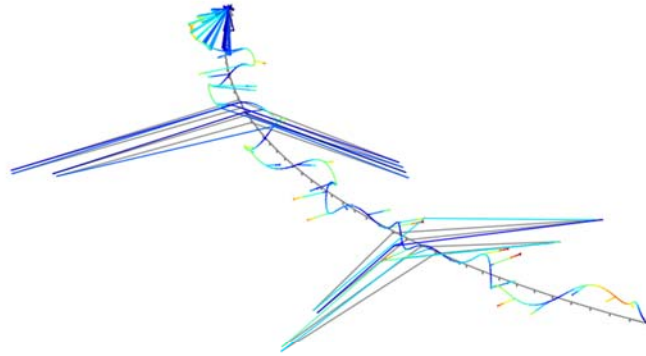

xy projection for mode 37

xz projection for mode 37

yz projection for mode 37

iso projection for mode 38

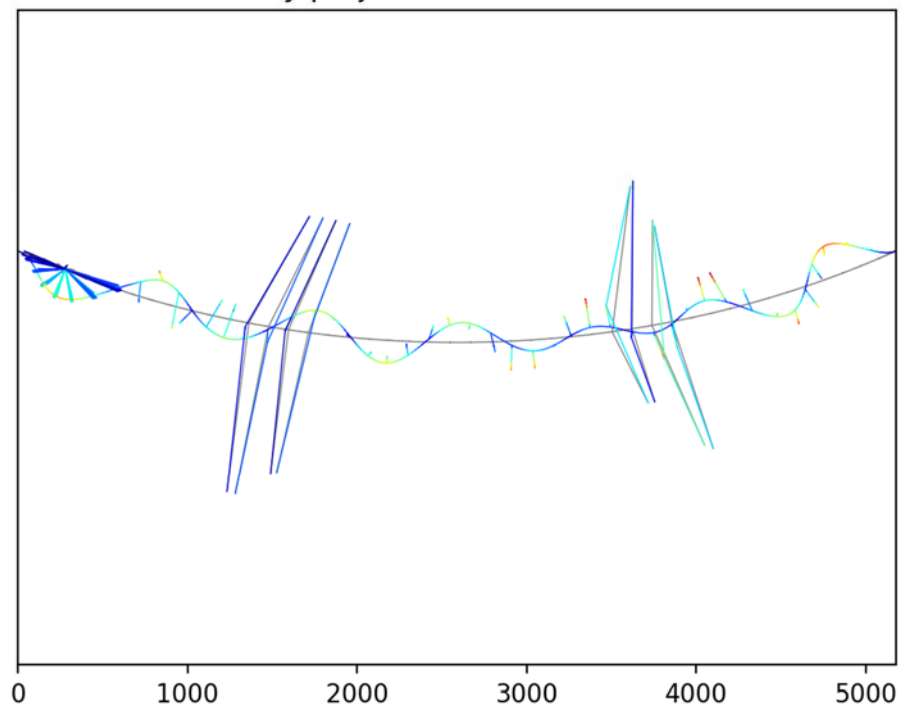xy projection for mode 38

xz projection for mode 38
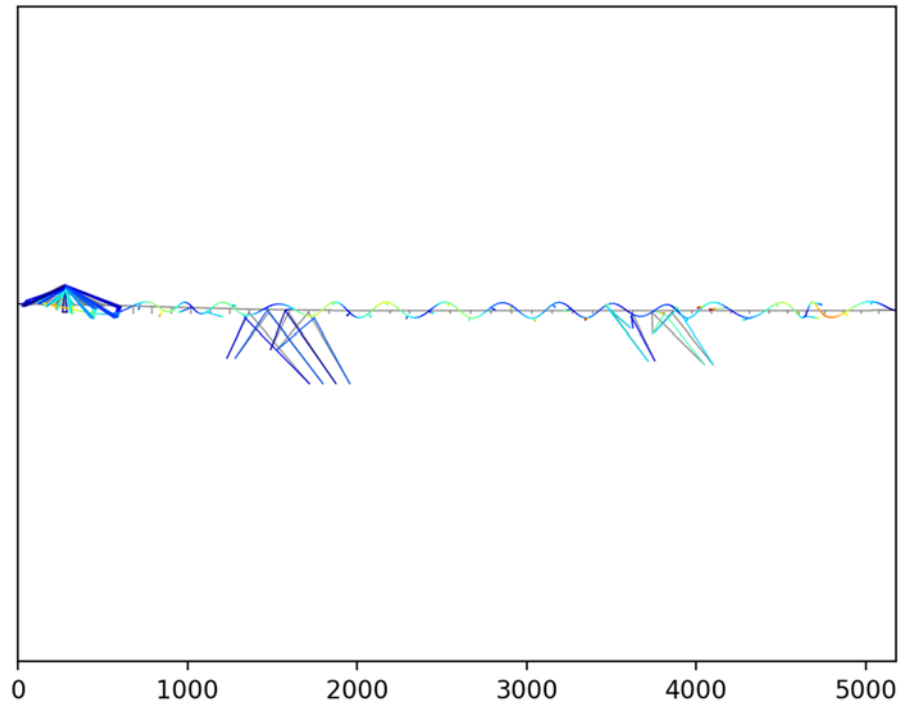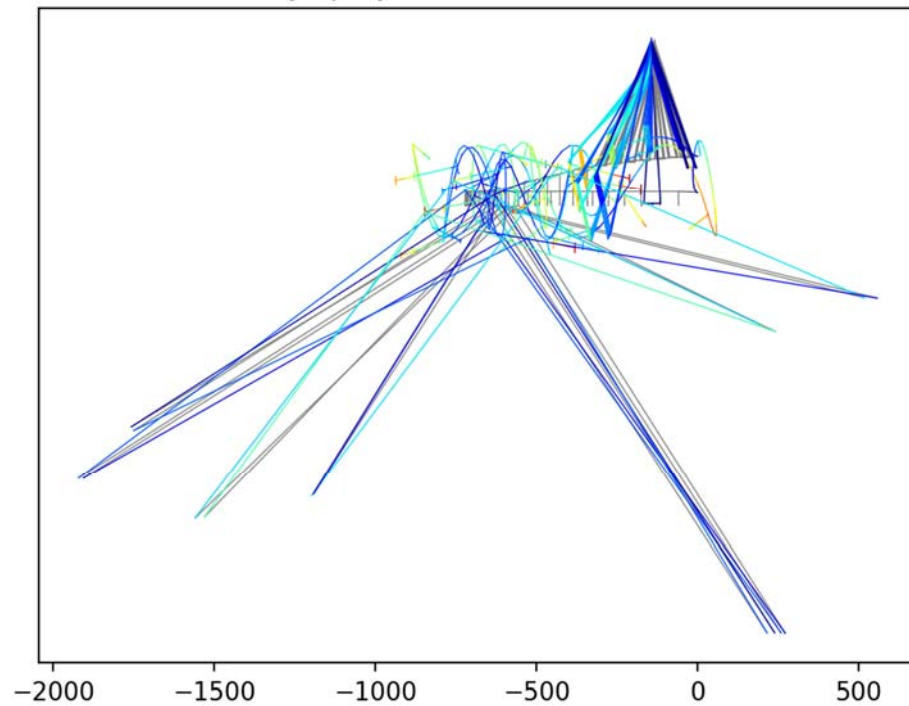

yz projection for mode 38

iso projection for mode 39
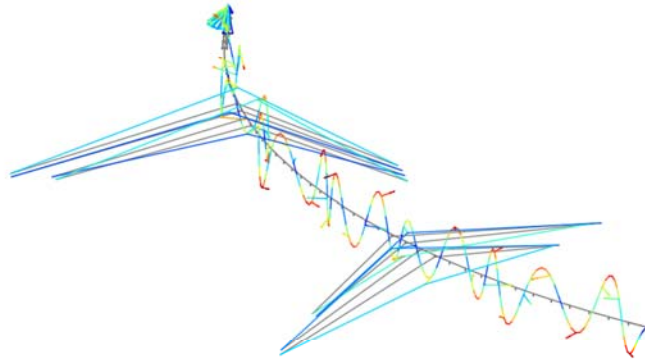

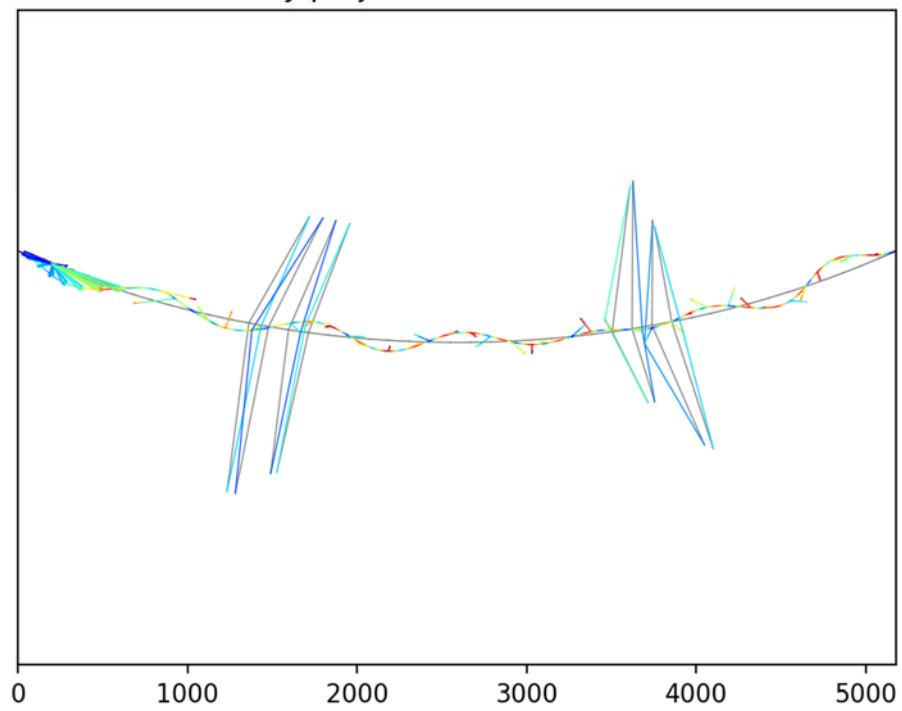xy projection for mode 39

xz projection for mode 39
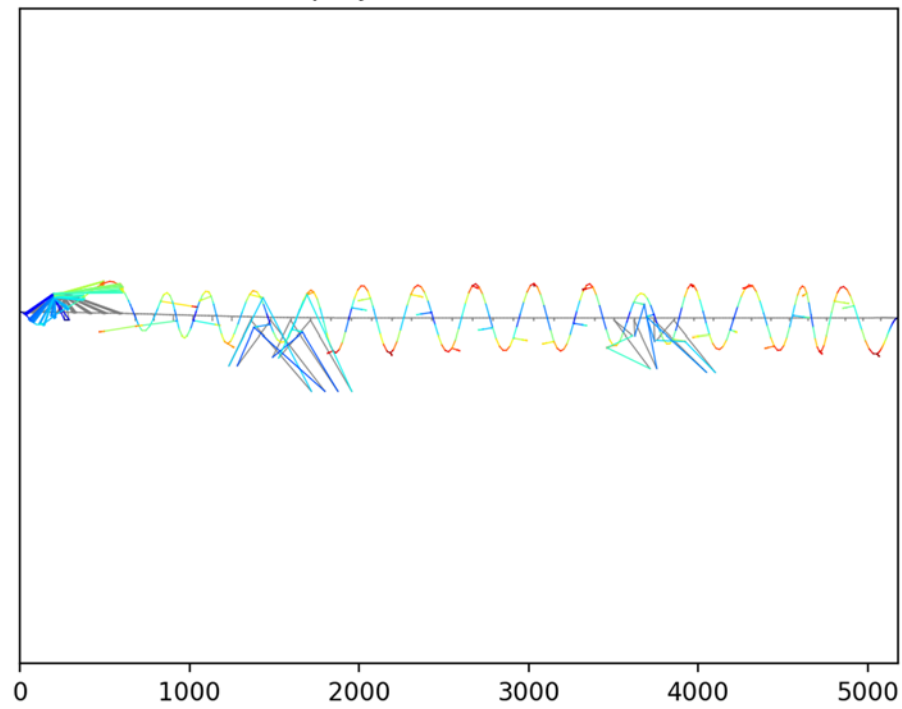

yz projection for mode 39

iso projection for mode 40
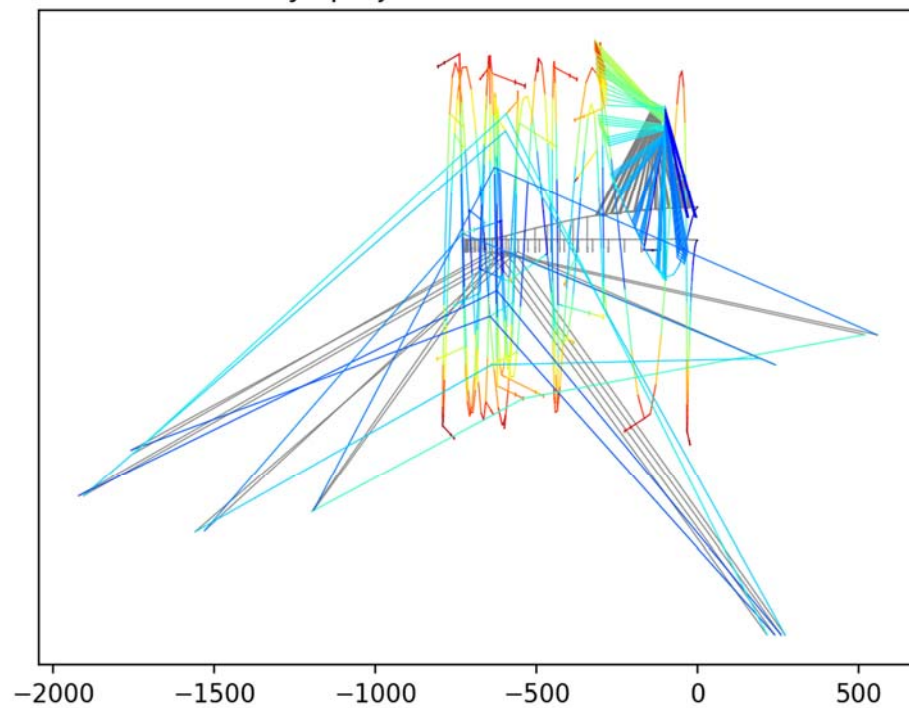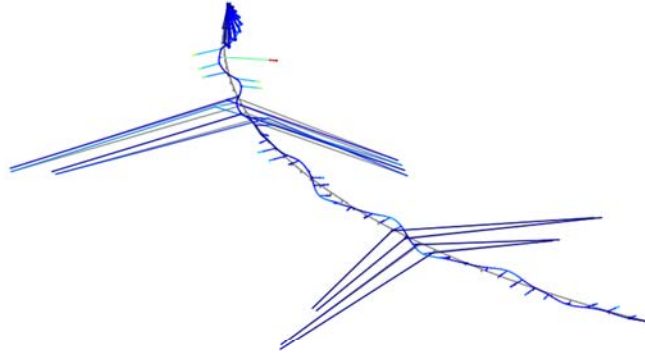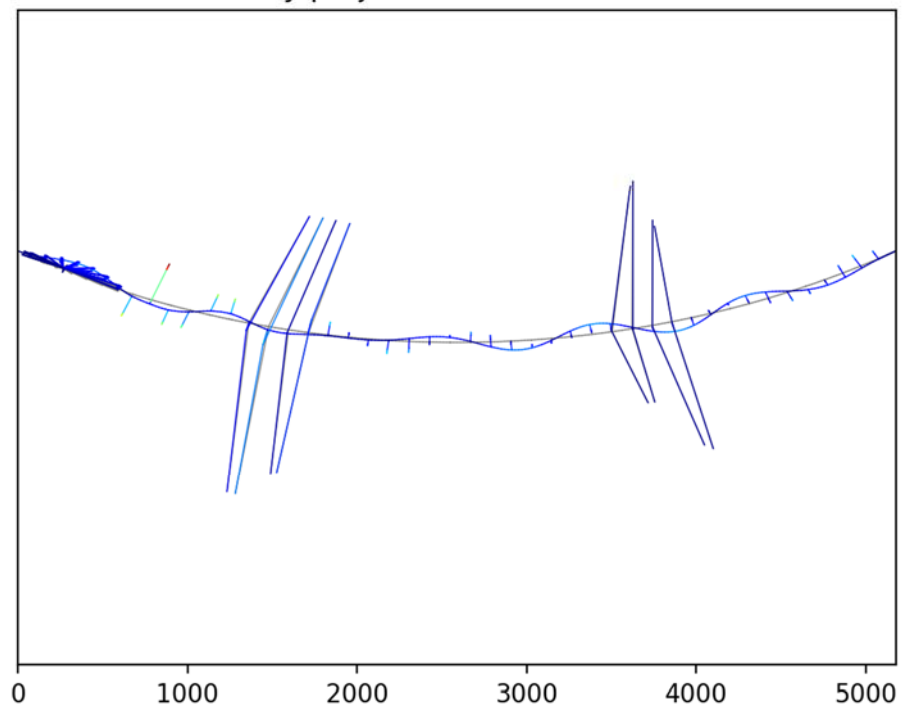

xy projection for mode 40

xz projection for mode 40

yz projection for mode 40

iso projection for mode 41

xy projection for mode 41

xz projection for mode 41
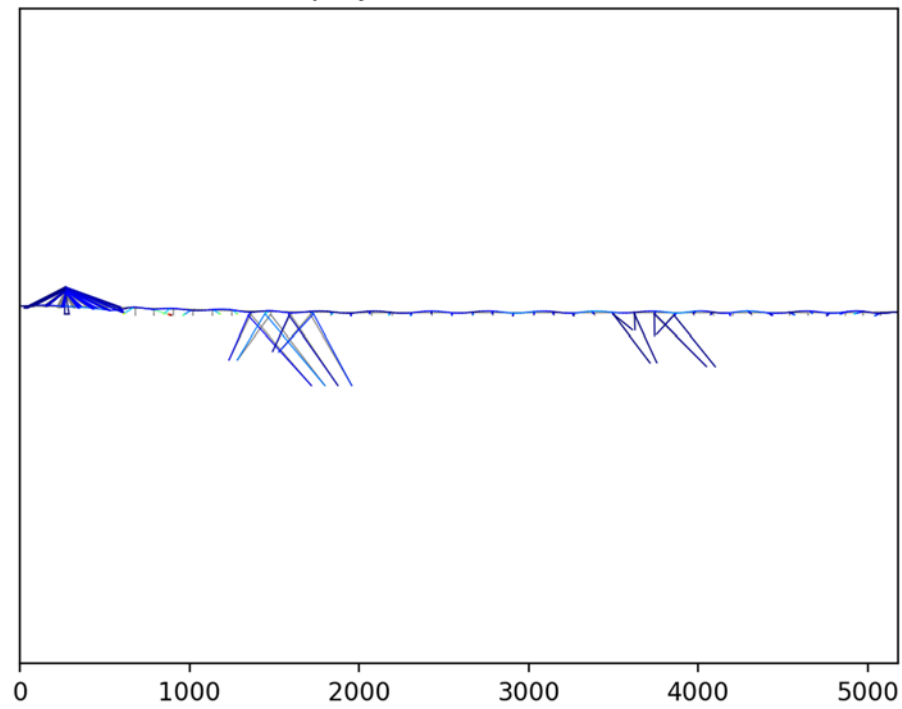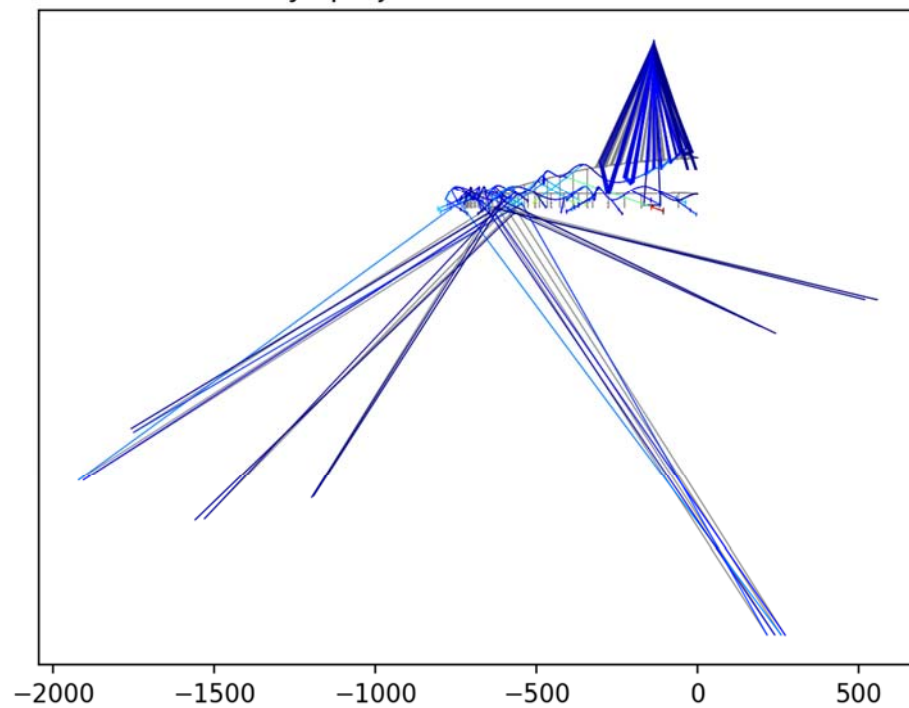

yz projection for mode 41

iso projection for mode 42
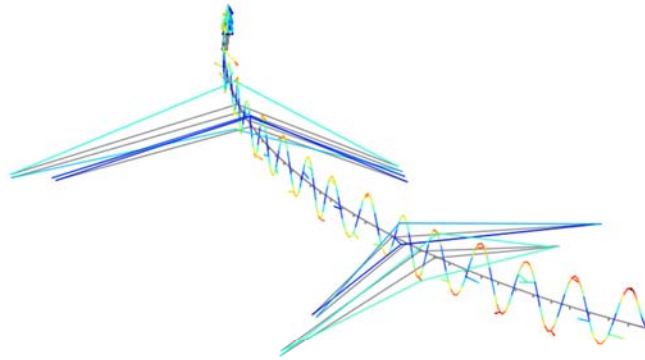

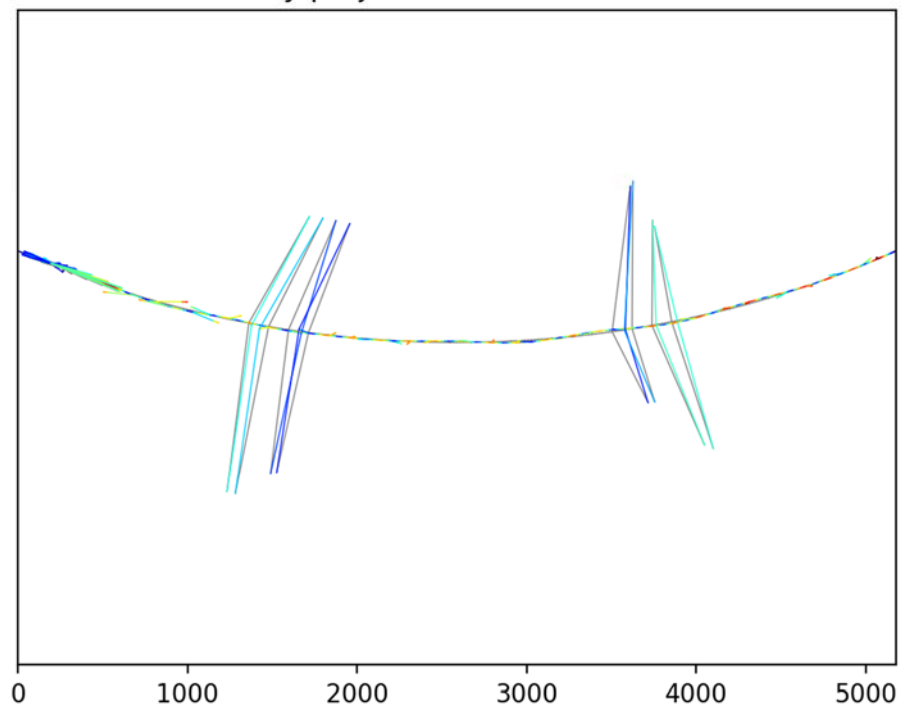xy projection for mode 42

xz projection for mode 42
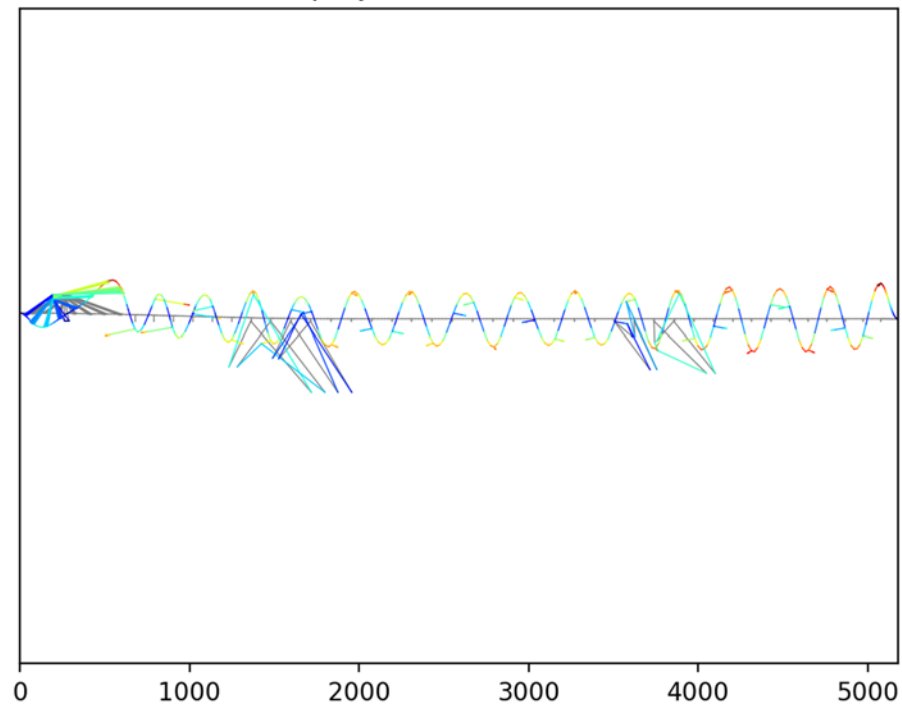

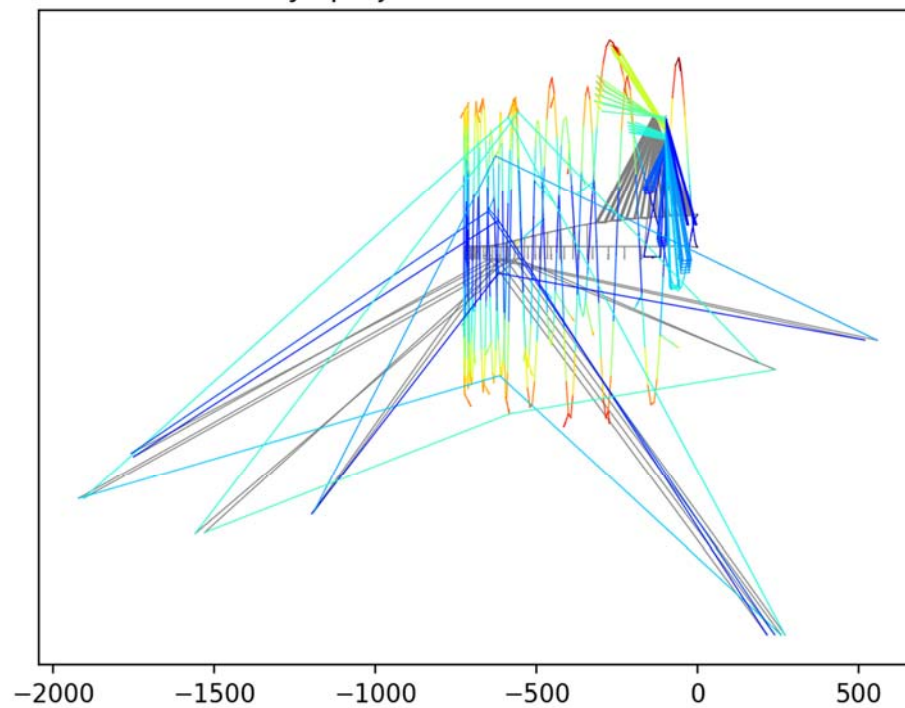## yz projection for mode 42

iso projection for mode 43
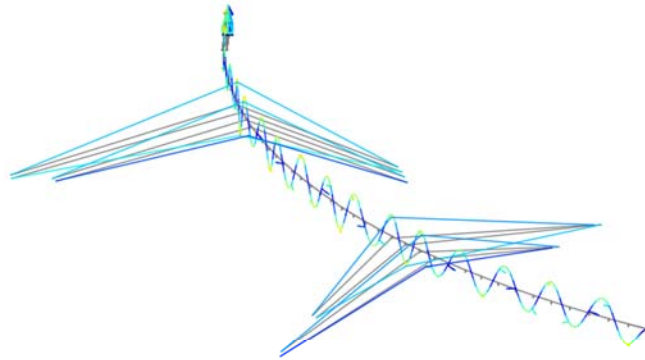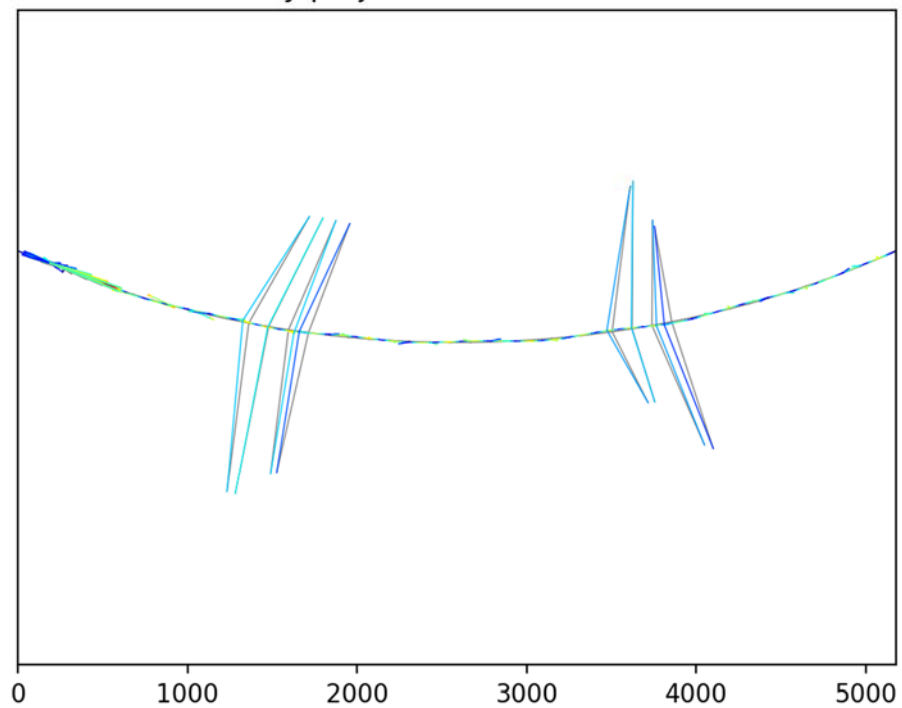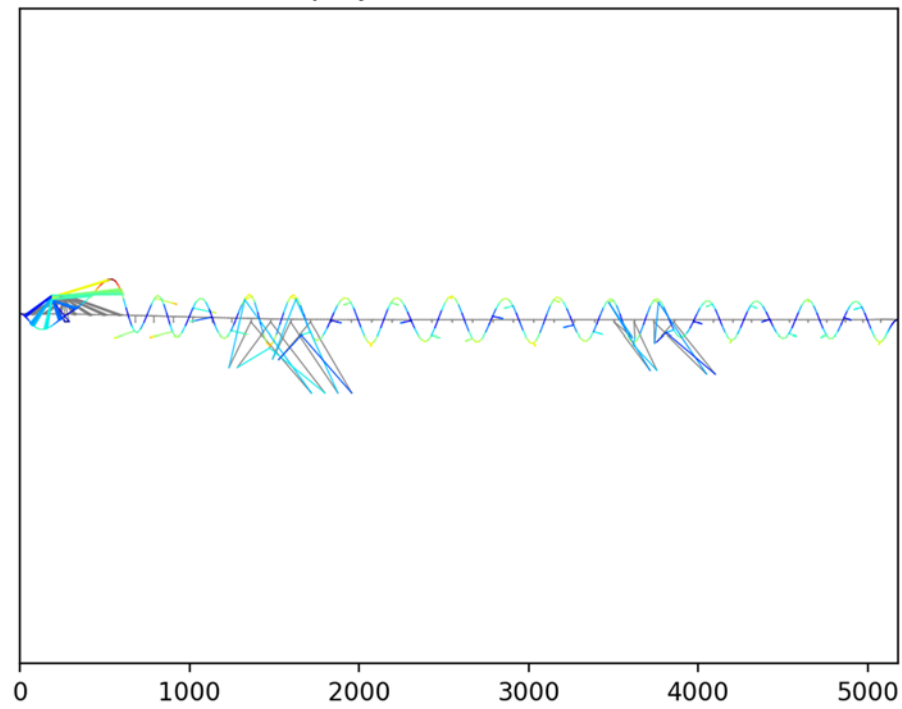

xy projection for mode 43

xz projection for mode 43

yz projection for mode 43

iso projection for mode 44

xy projection for mode 44

xz projection for mode 44
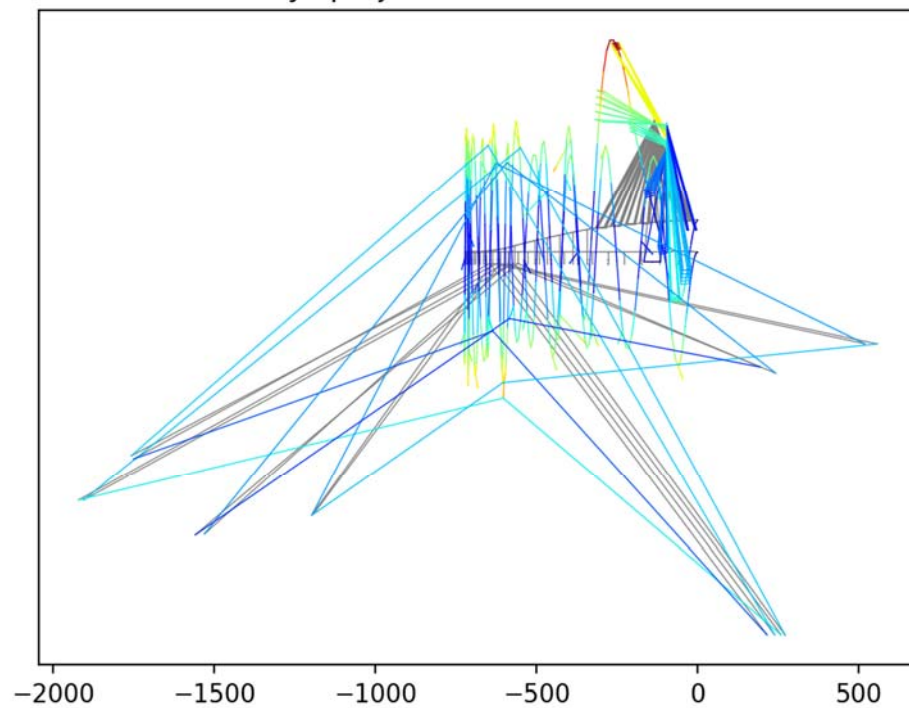

yz projection for mode 44

iso projection for mode 45
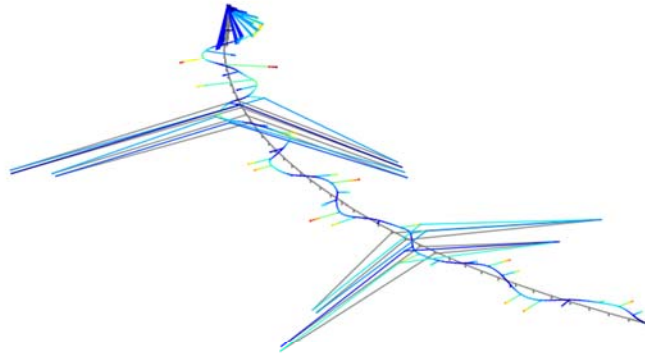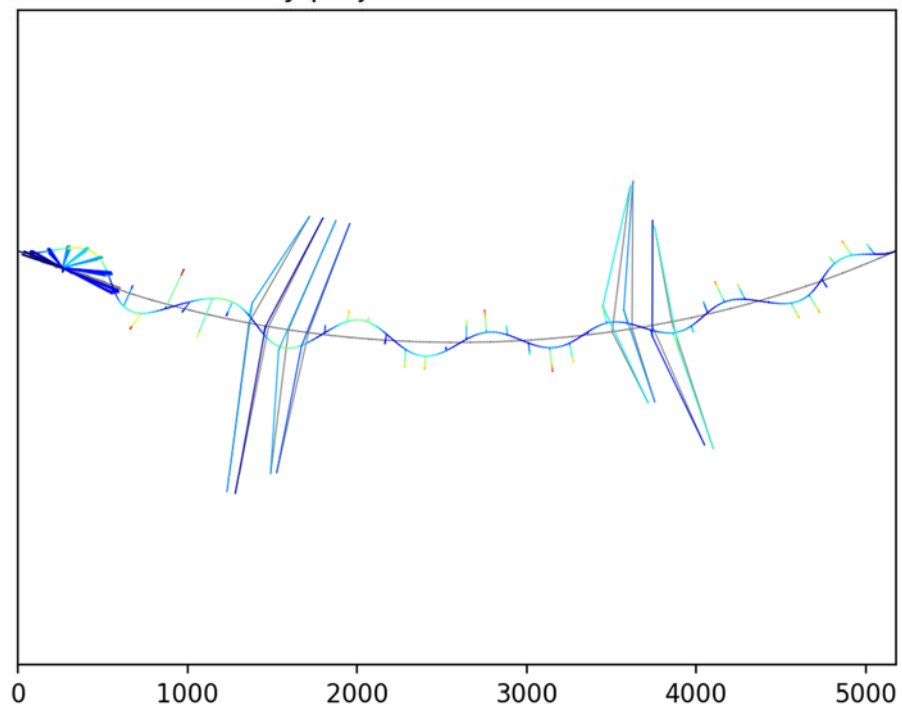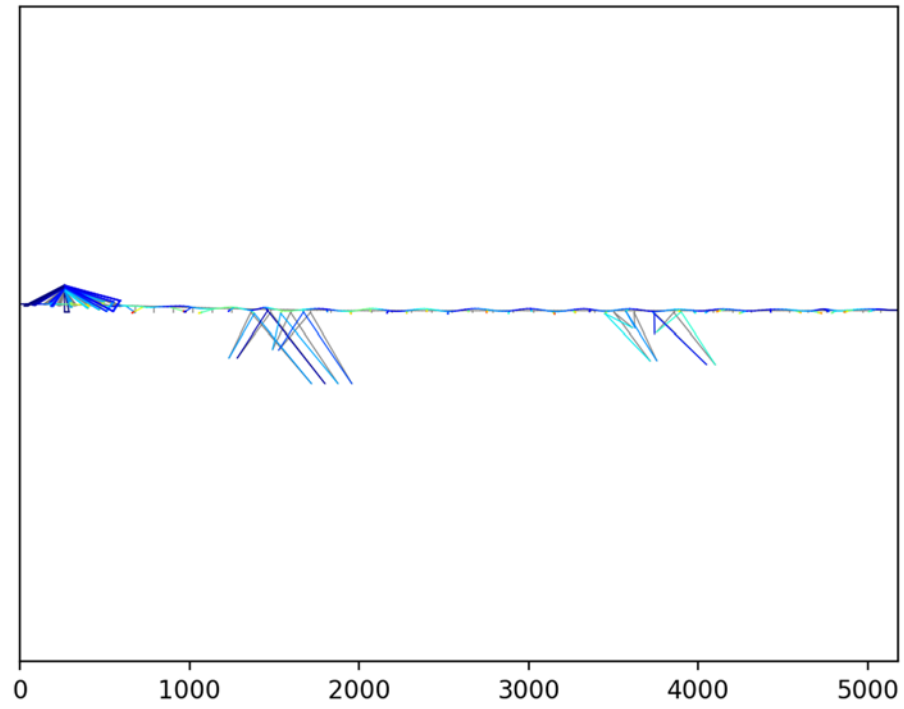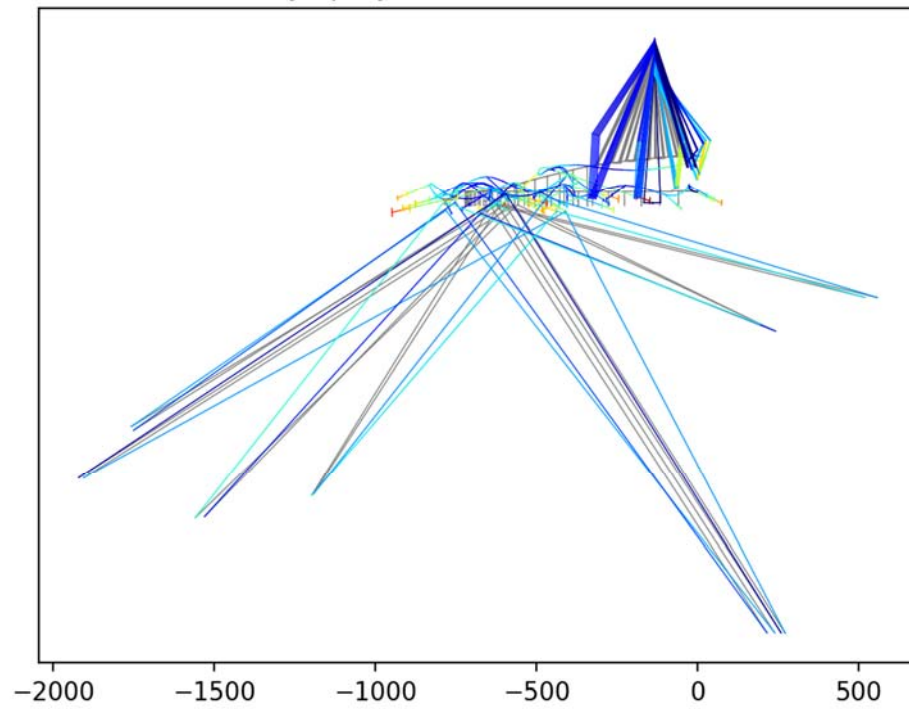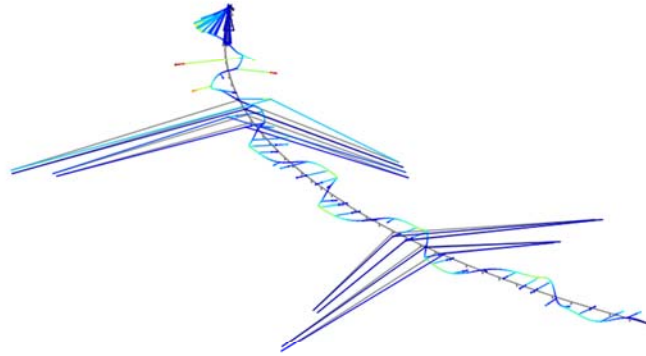

xy projection for mode 45

xz projection for mode 45

yz projection for mode 45

iso projection for mode 46

xy projection for mode 46

xz projection for mode 46

yz projection for mode 46

iso projection for mode 47

xy projection for mode 47
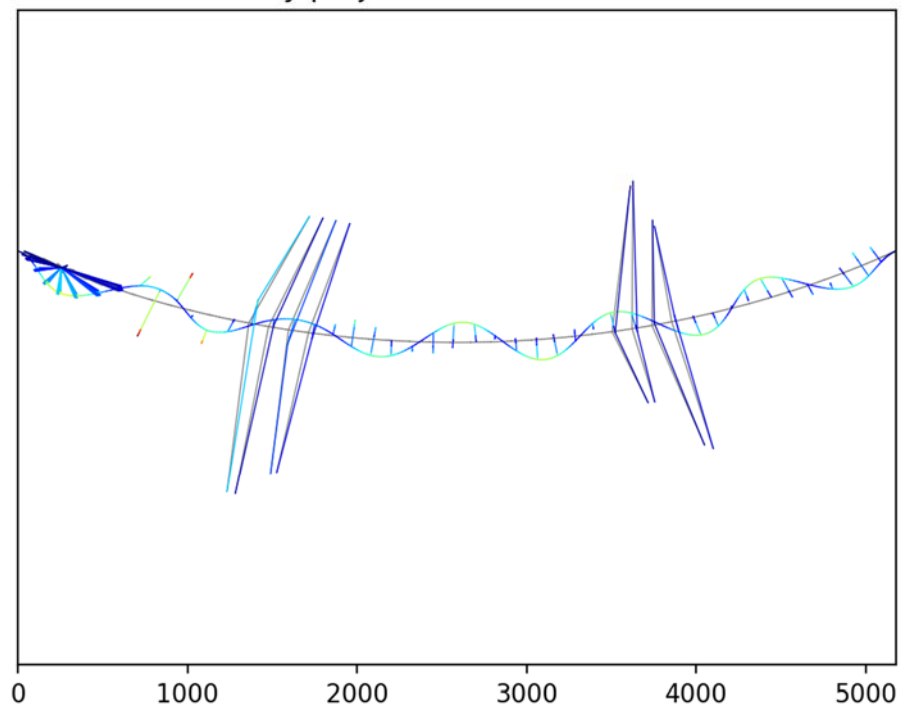
xz projection for mode 47
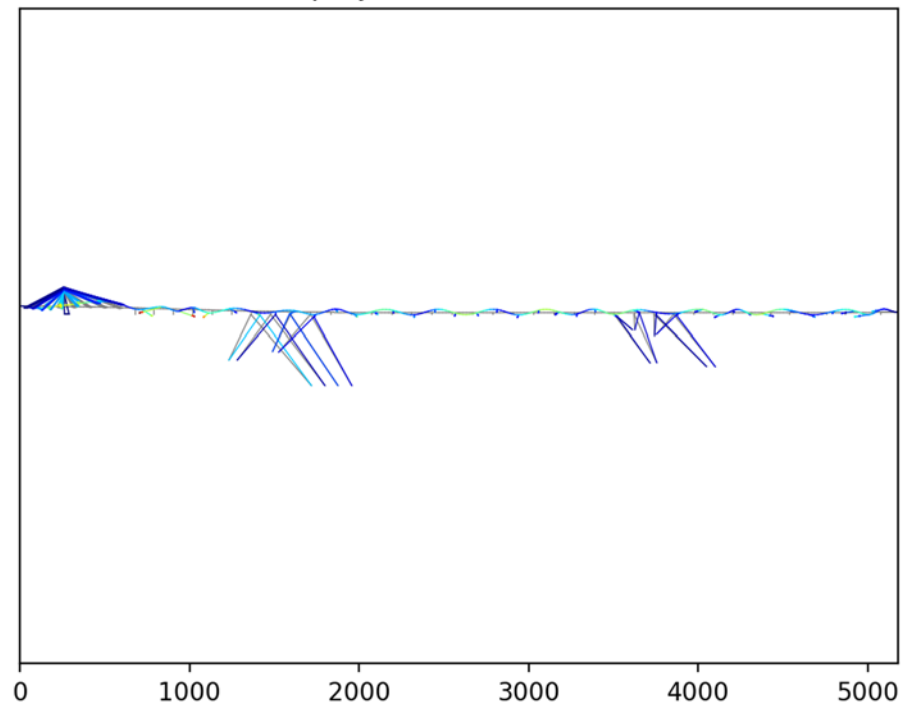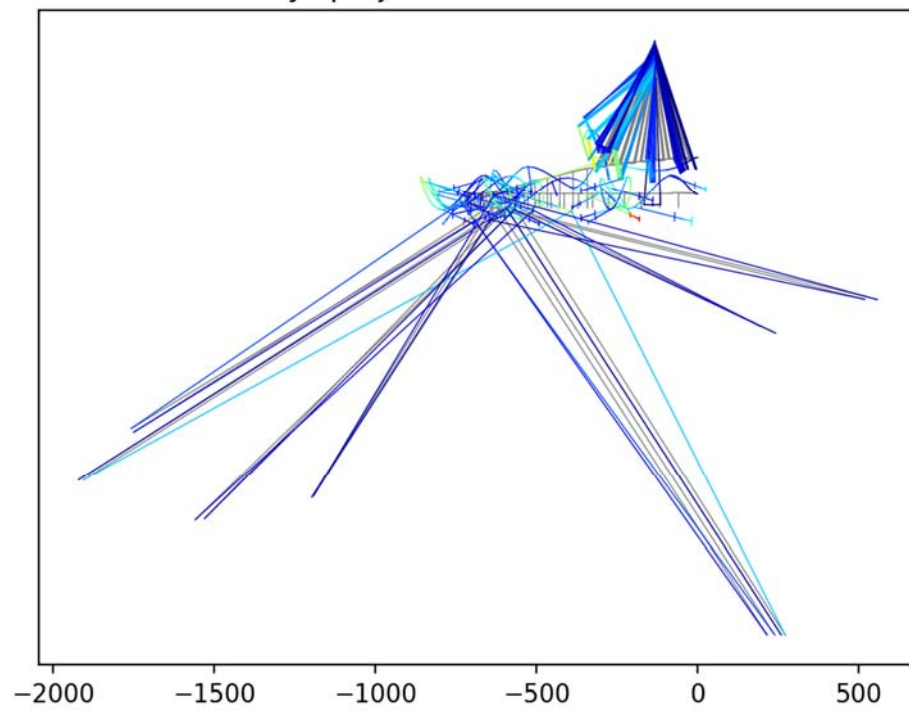

yz projection for mode 47

iso projection for mode 48
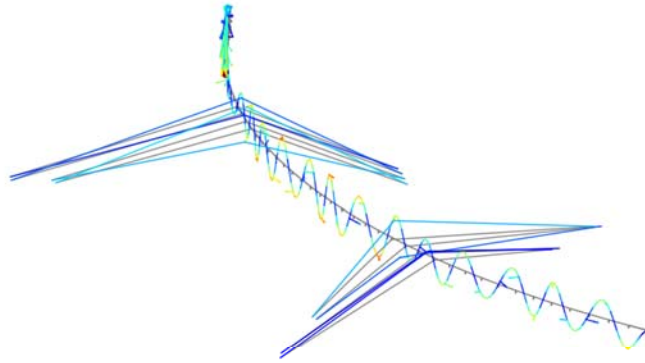

xy projection for mode 48
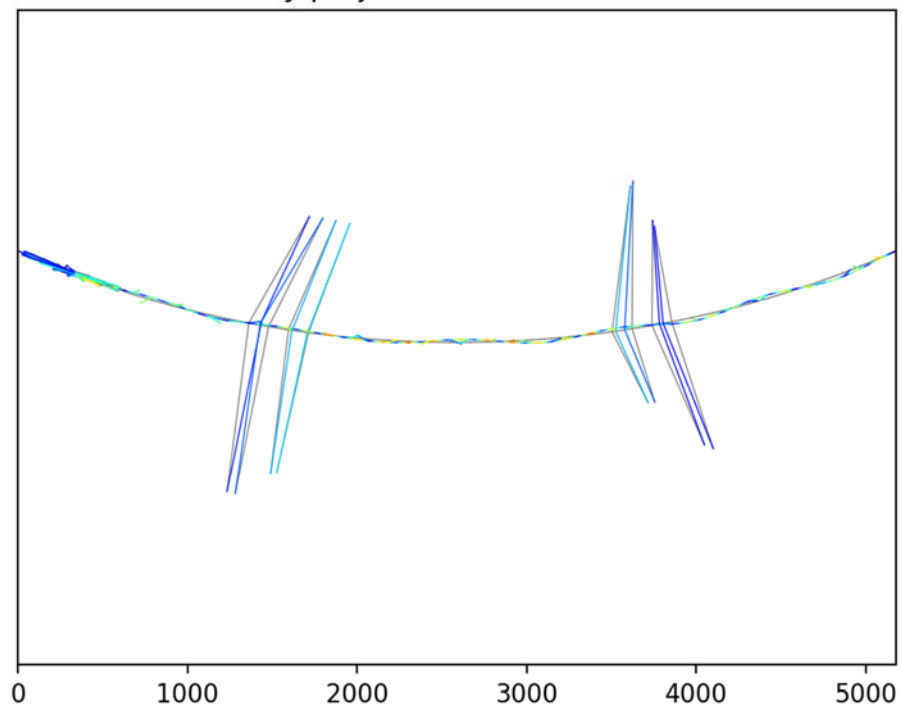
xz projection for mode 48
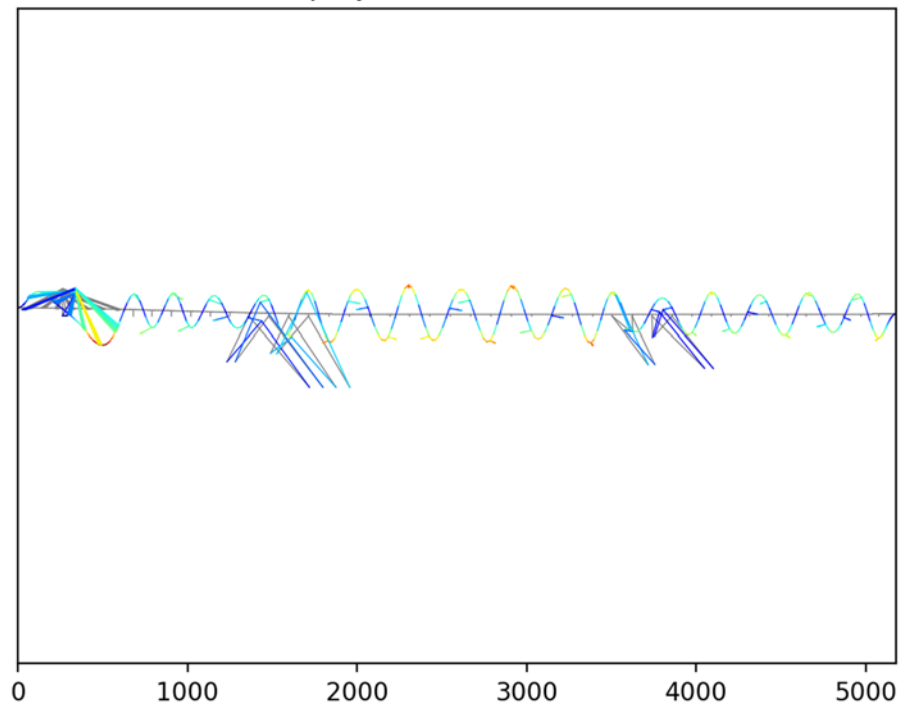

yz projection for mode 48

iso projection for mode 49

xy projection for mode 49
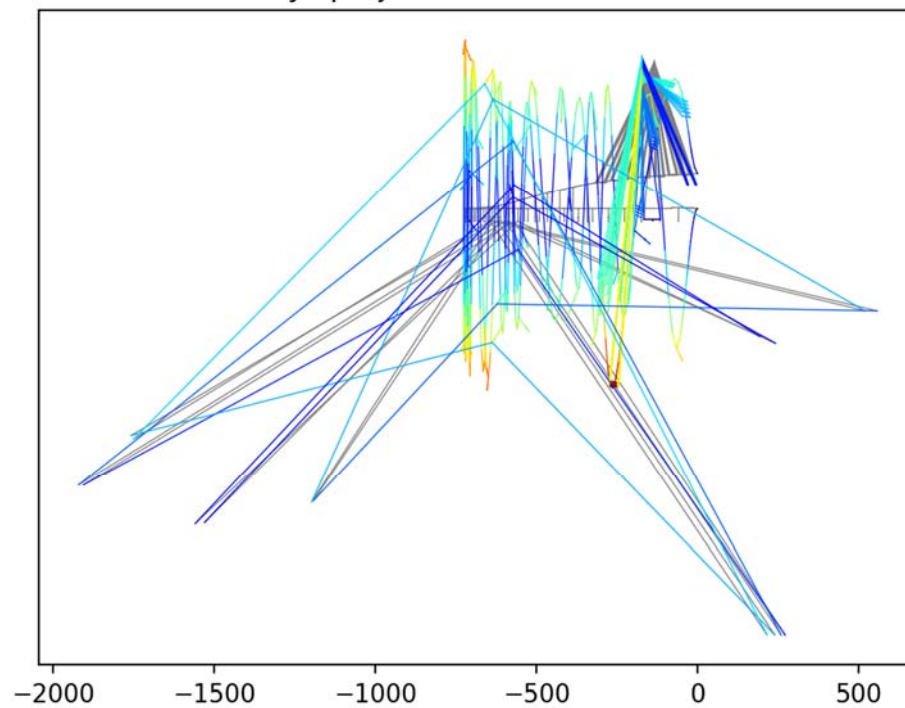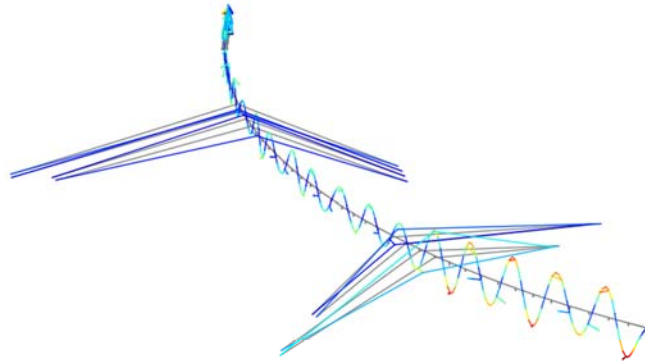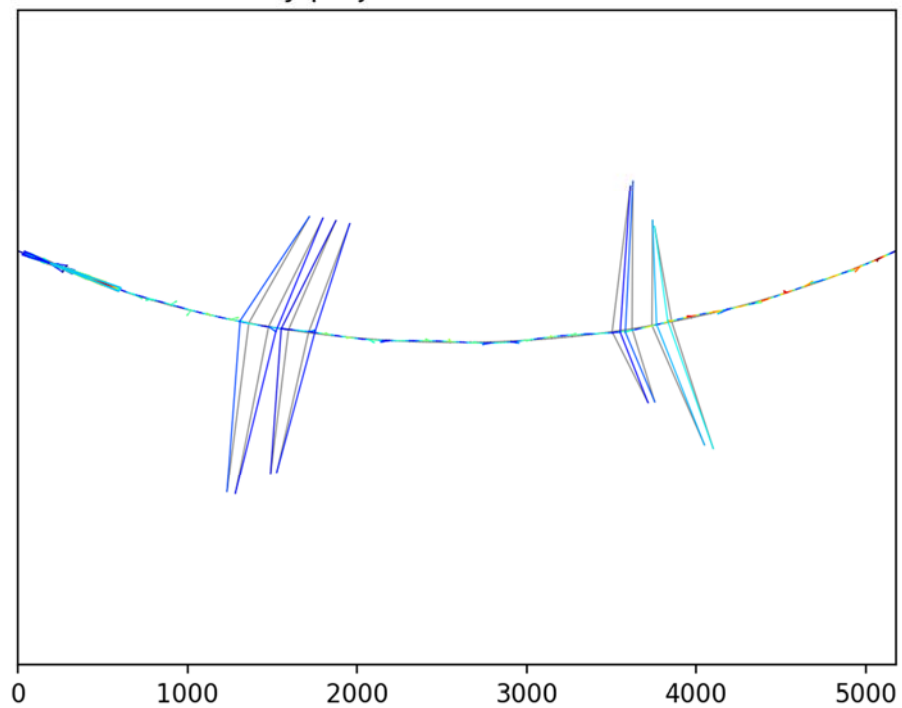
xz projection for mode 49
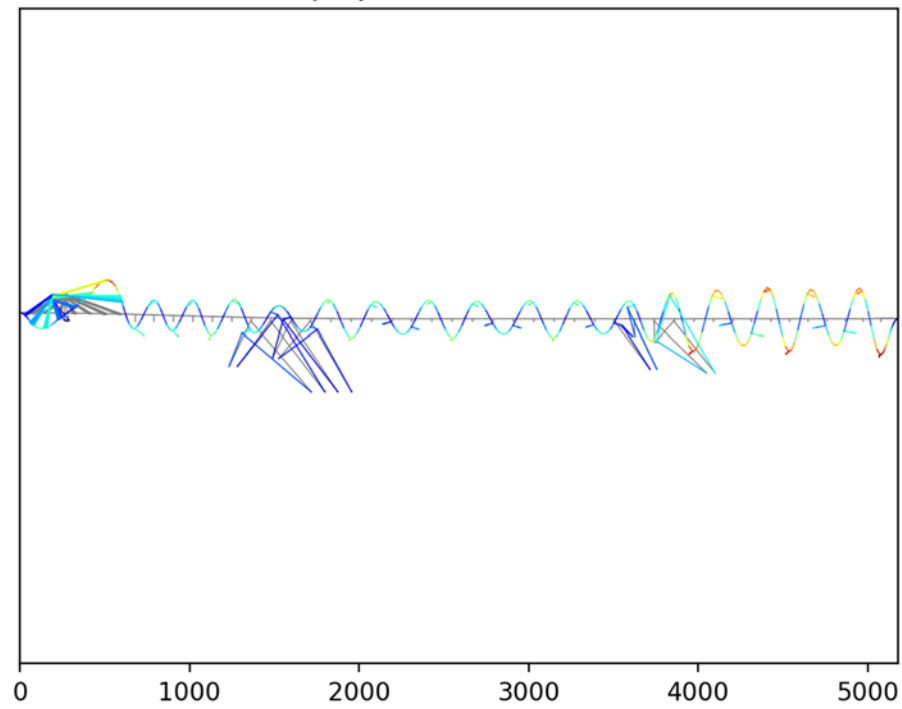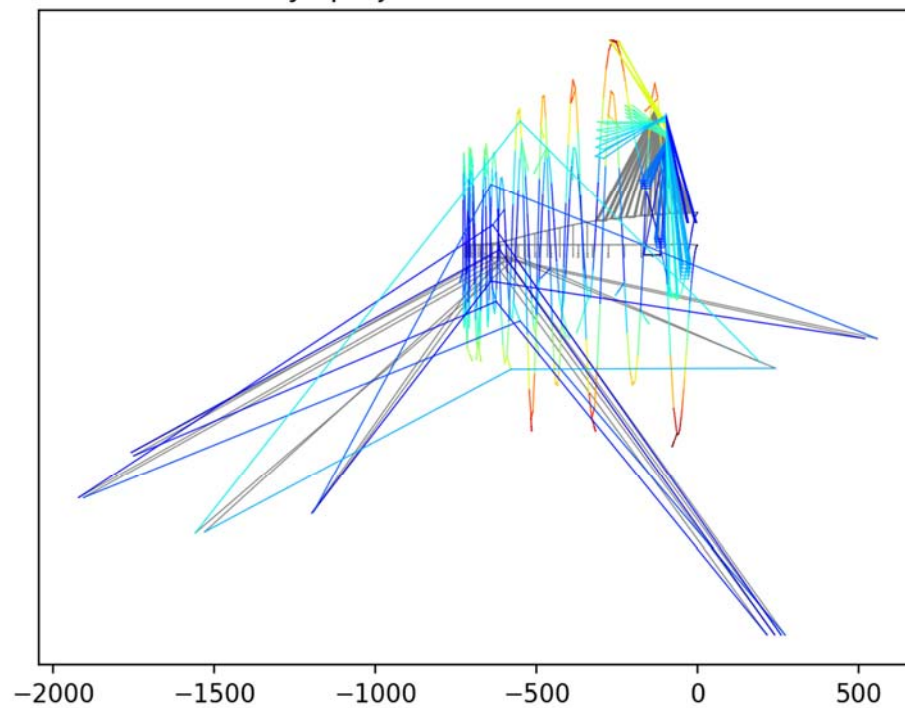

yz projection for mode 49

iso projection for mode 50
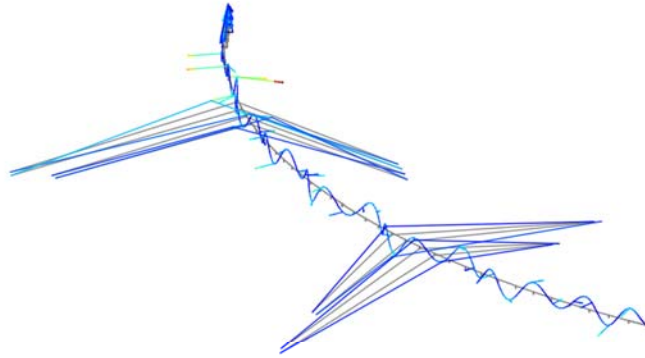

xy projection for mode 50
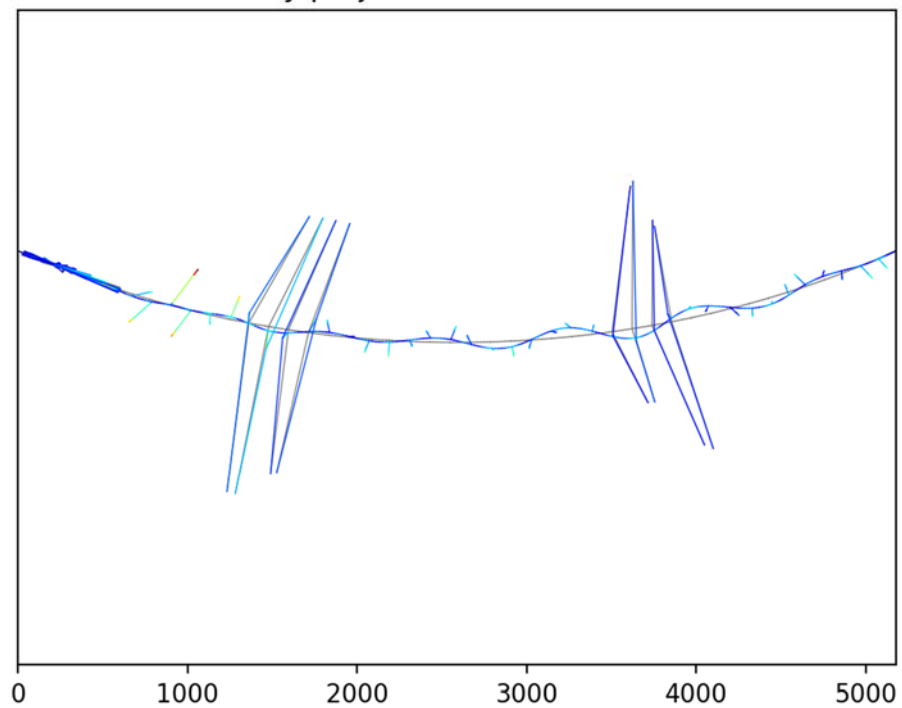
xz projection for mode 50
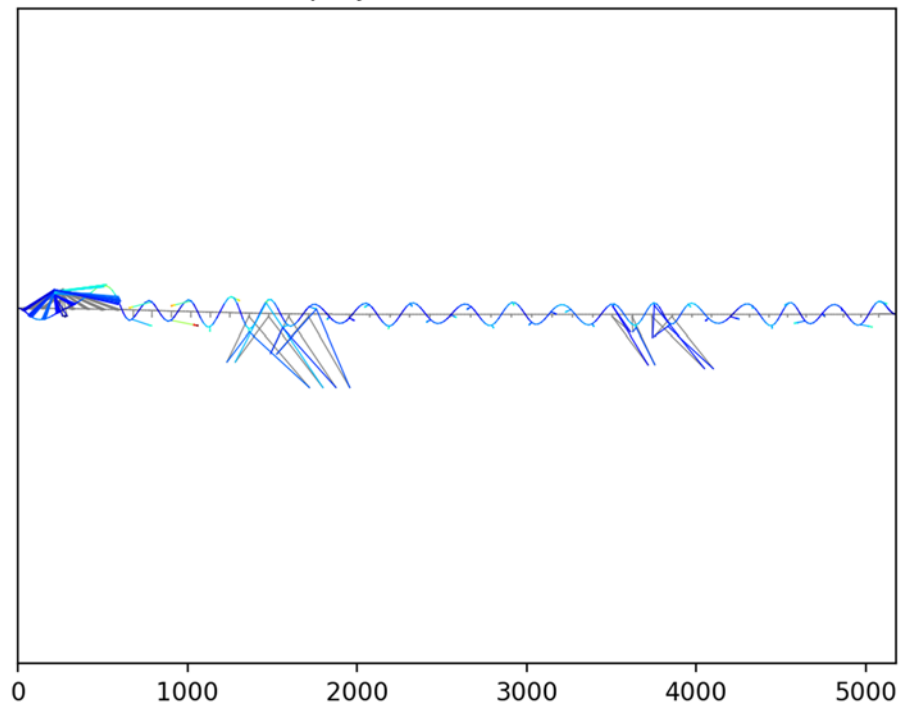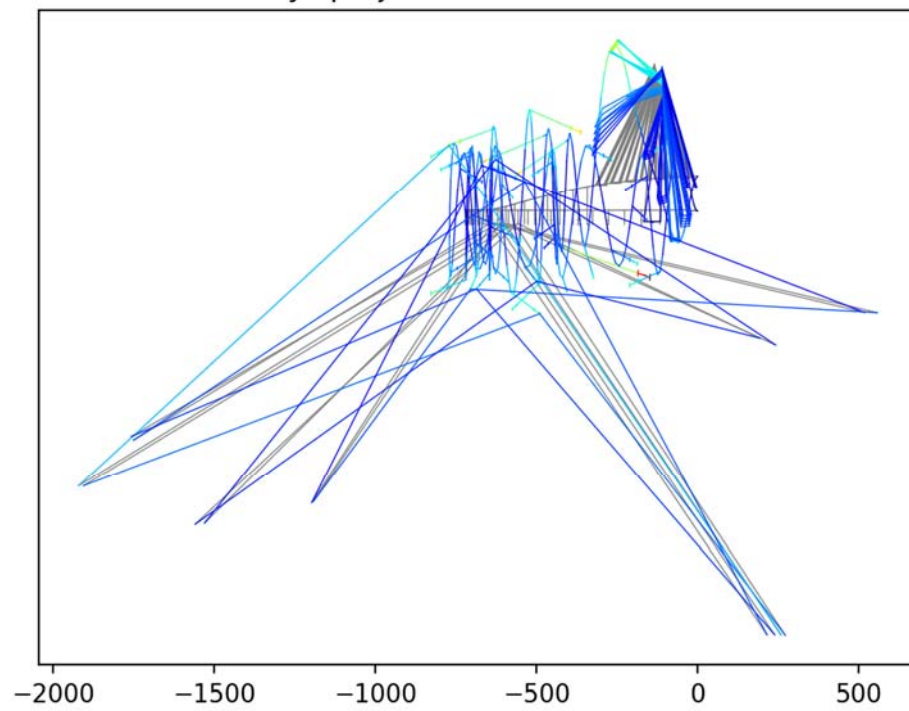

yz projection for mode 50

iso projection for mode 51
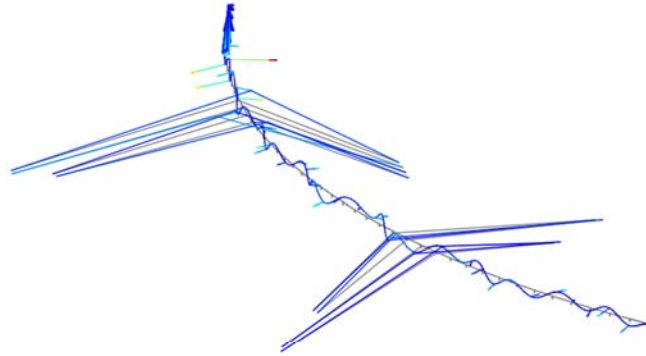

xy projection for mode 51
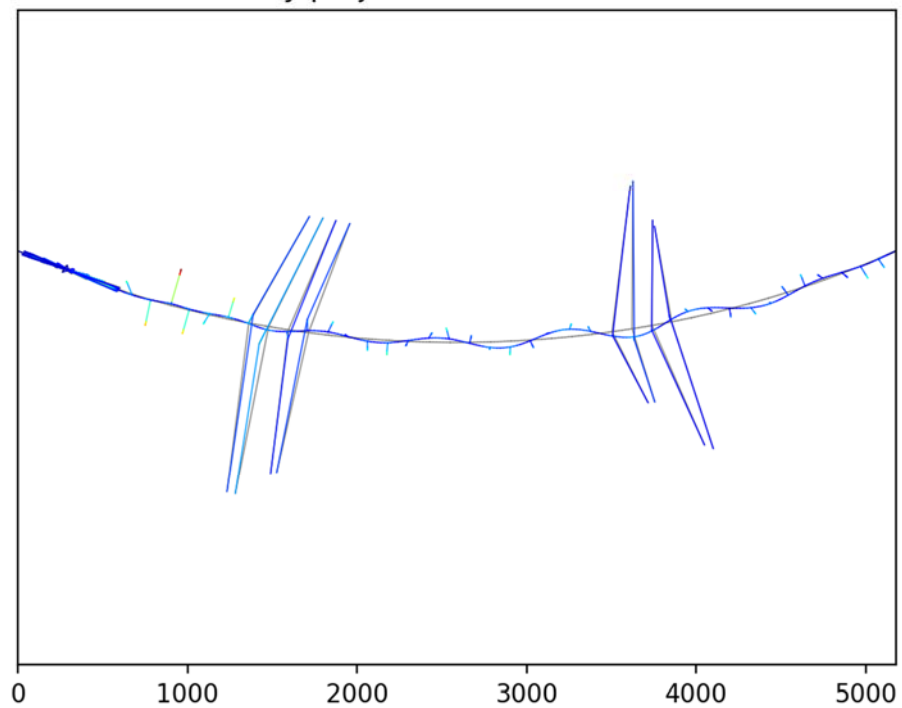
xz projection for mode 51
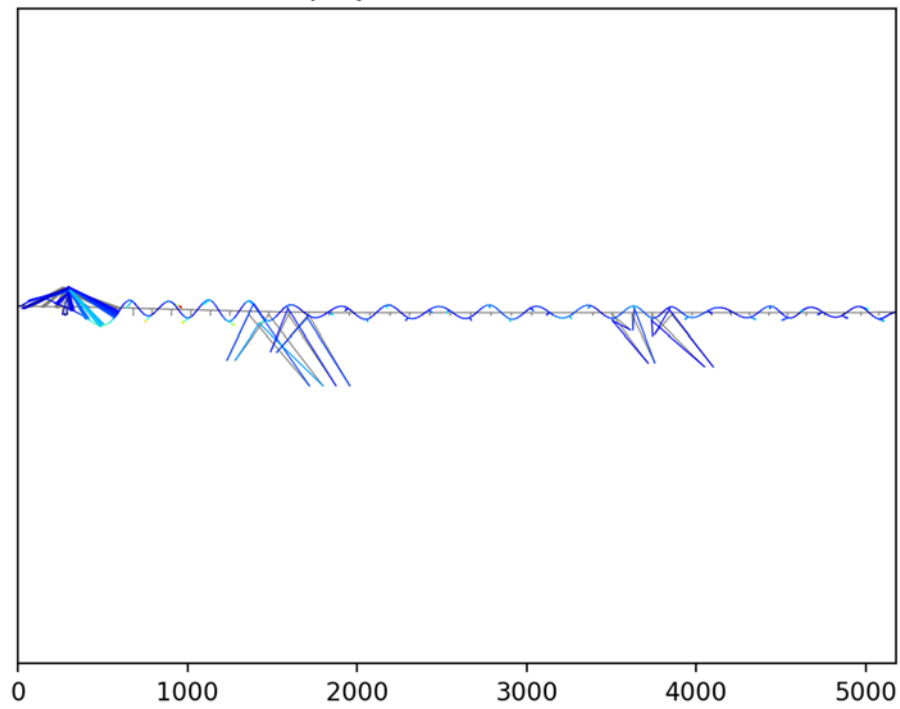

yz projection for mode 51

iso projection for mode 52

xy projection for mode 52

xz projection for mode 52

yz projection for mode 52

iso projection for mode 53

xy projection for mode 53
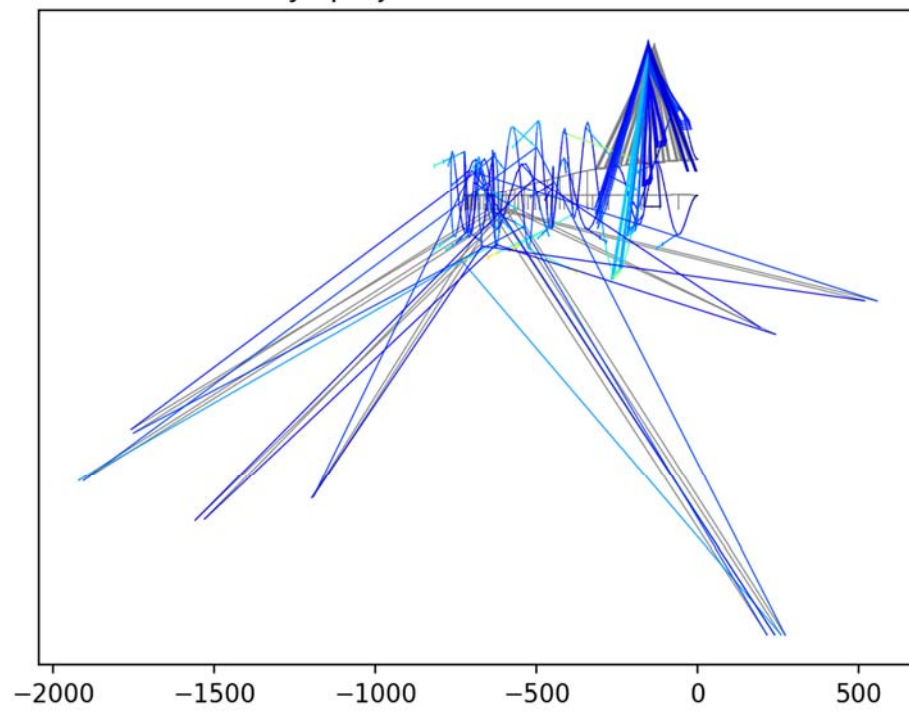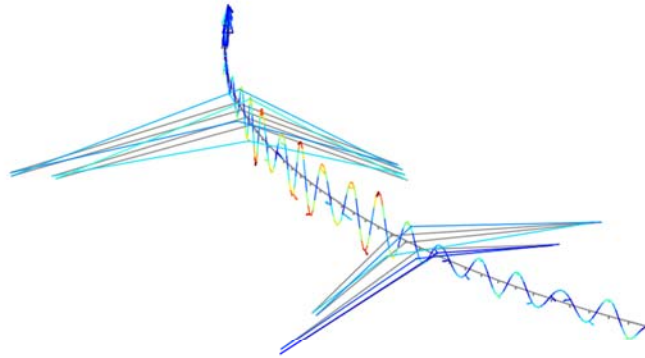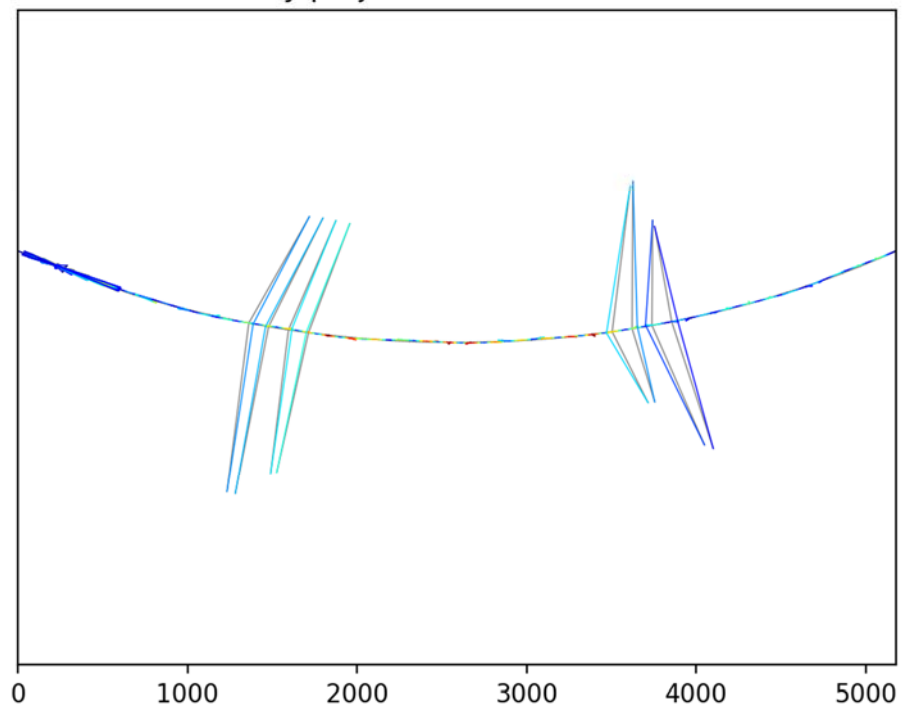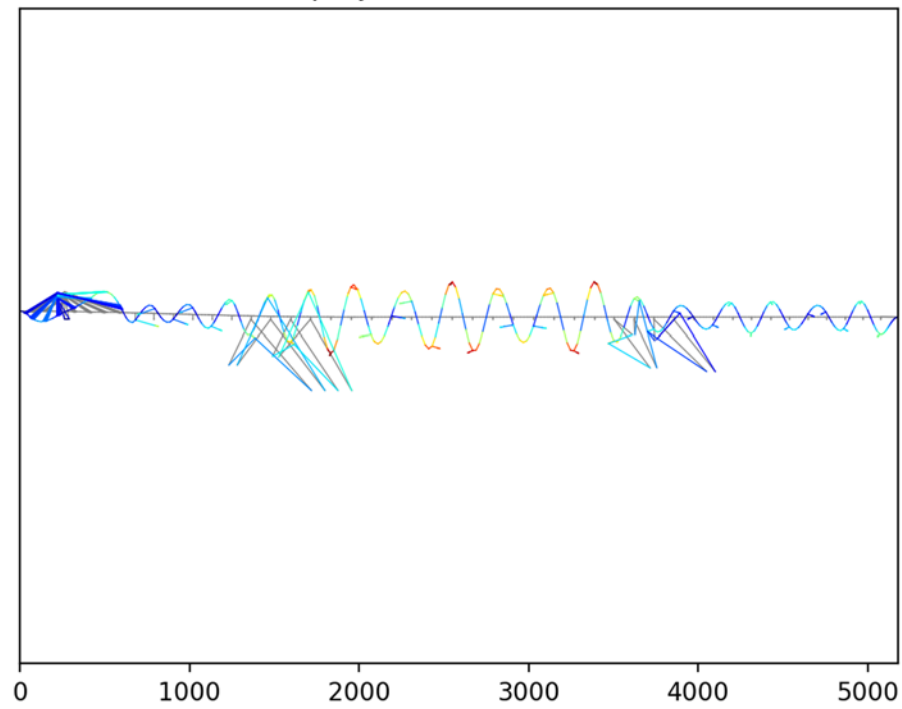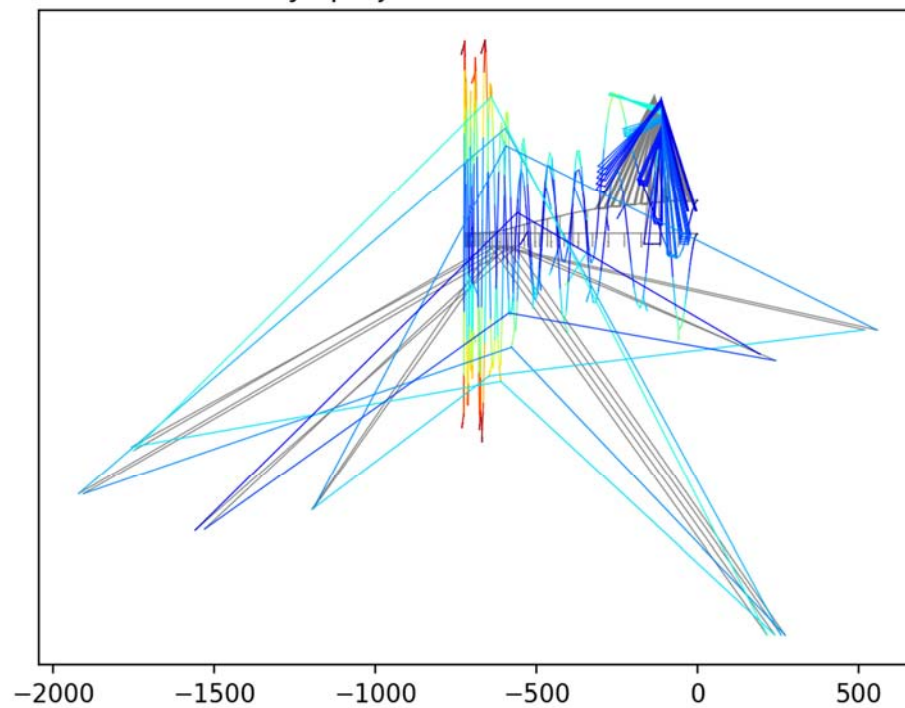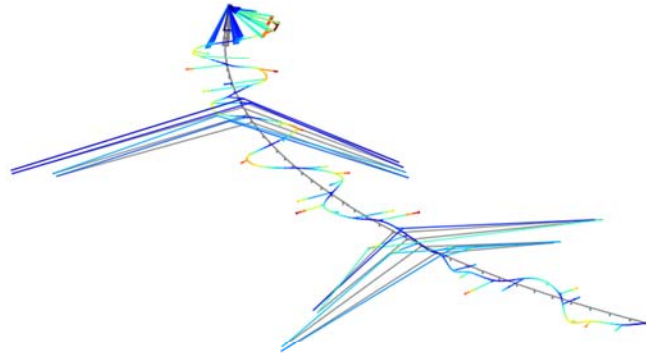
xz projection for mode 53

yz projection for mode 53

iso projection for mode 54

xy projection for mode 54

xz projection for mode 54

yz projection for mode 54

iso projection for mode 55

xy projection for mode 55
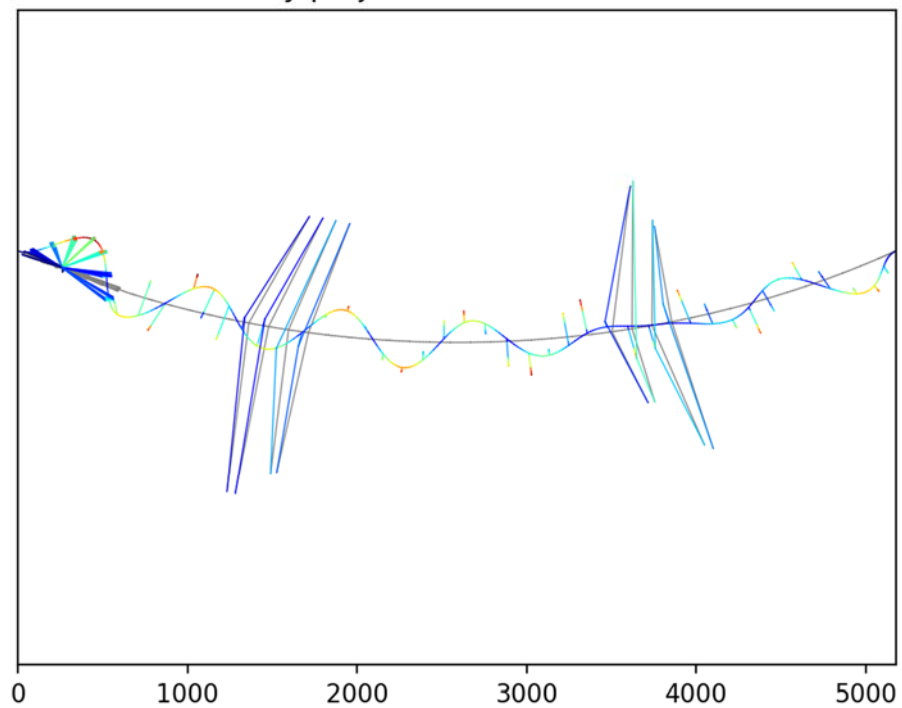
xz projection for mode 55
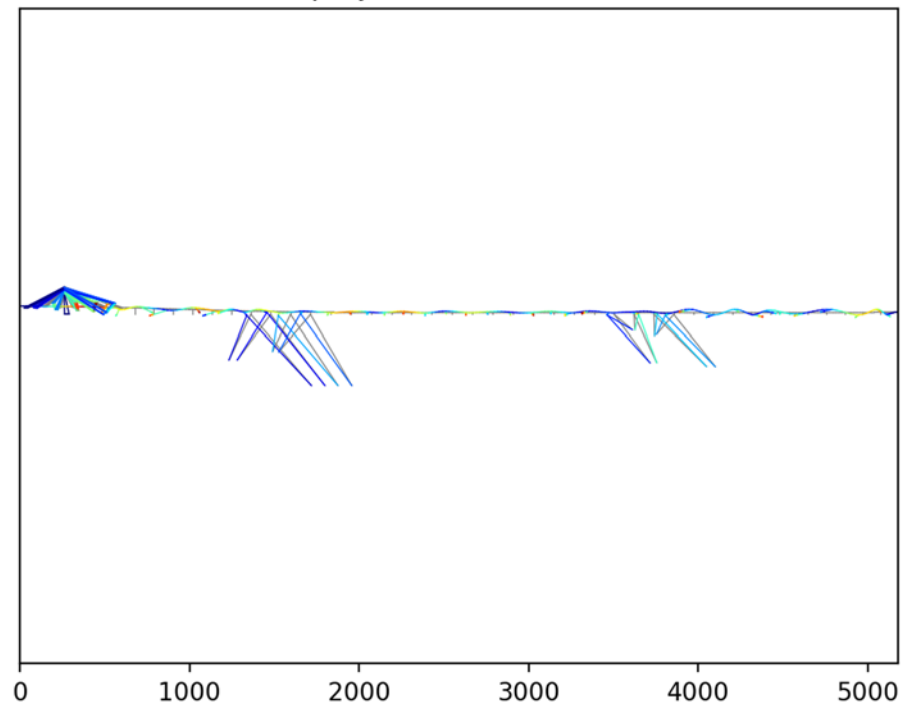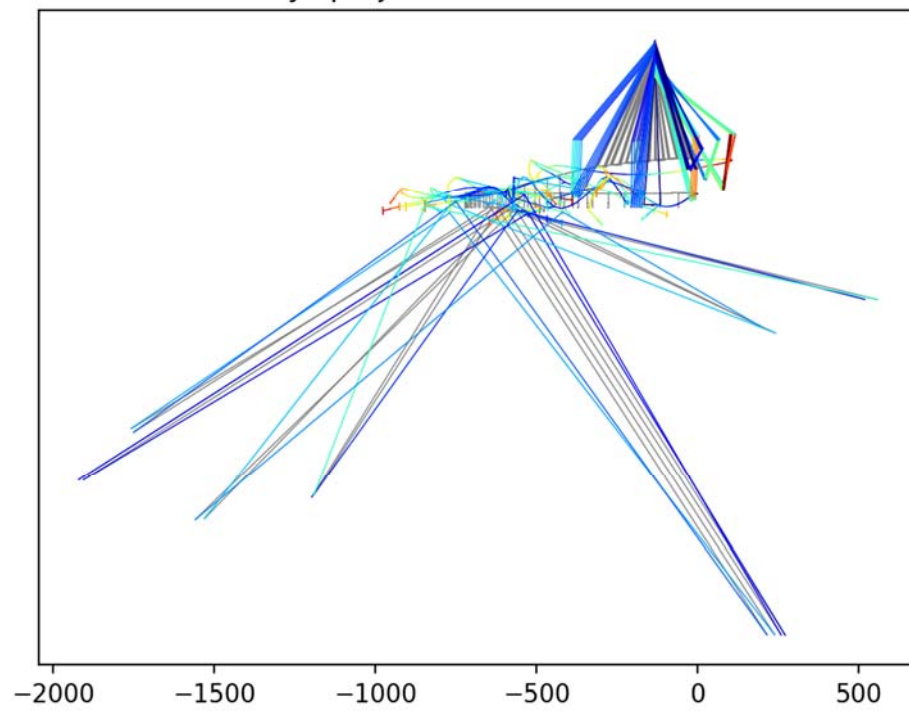

yz projection for mode 55

iso projection for mode 56
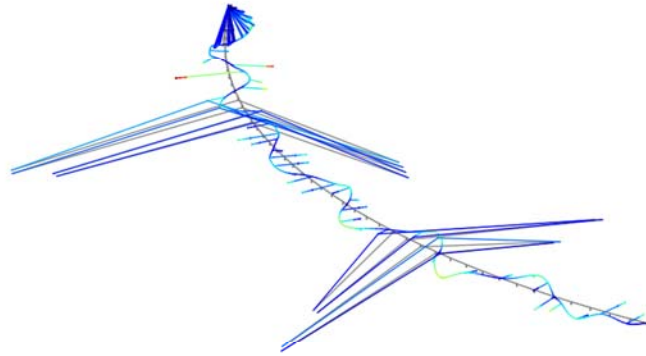

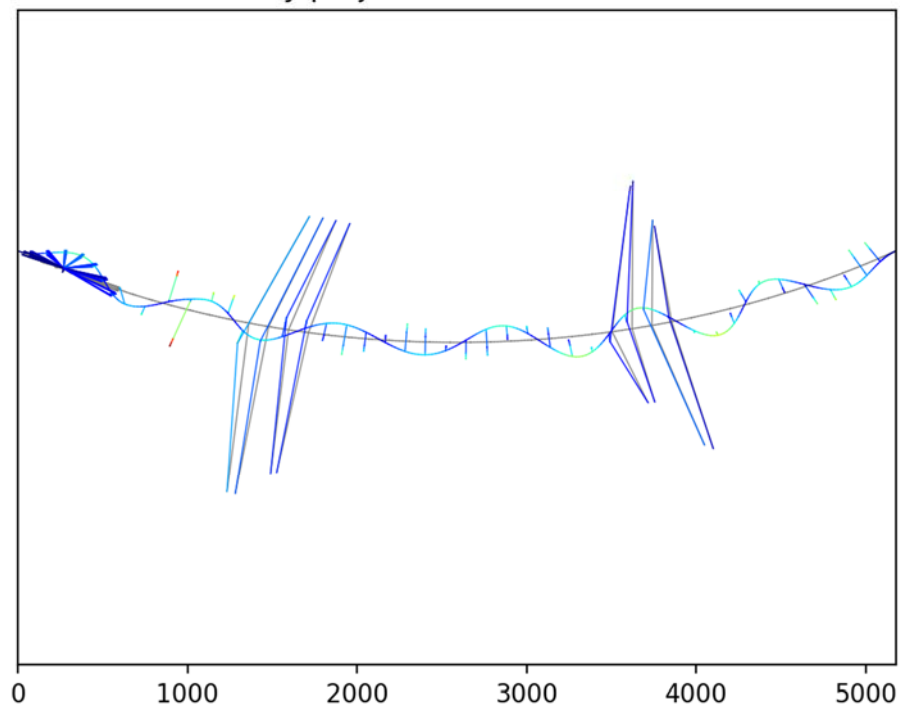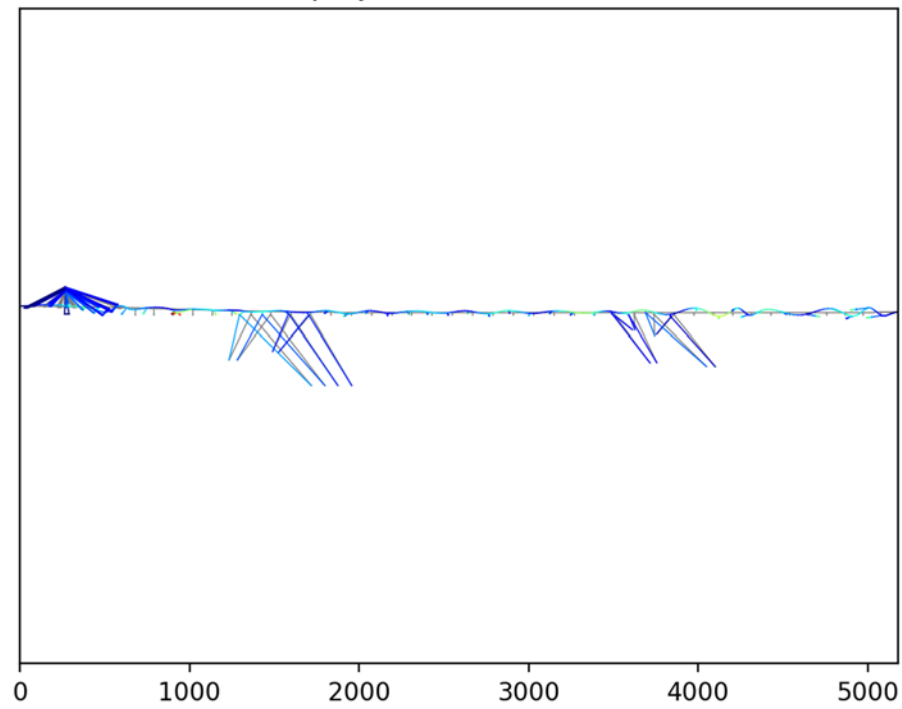xy projection for mode 56

xz projection for mode 56

yz projection for mode 56

iso projection for mode 57

xy projection for mode 57
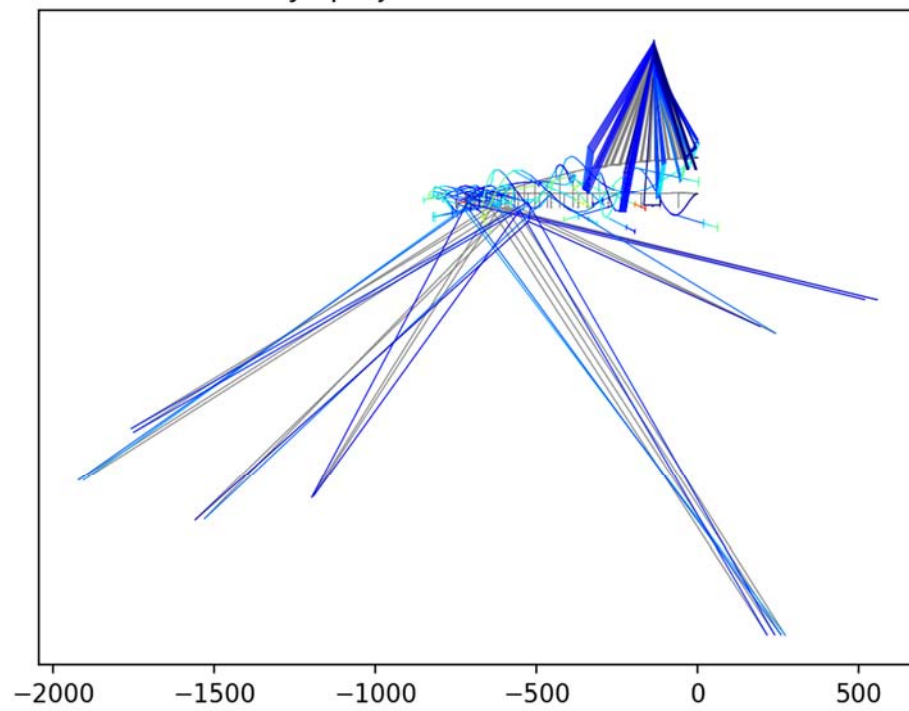
xz projection for mode 57

yz projection for mode 57

iso projection for mode 58
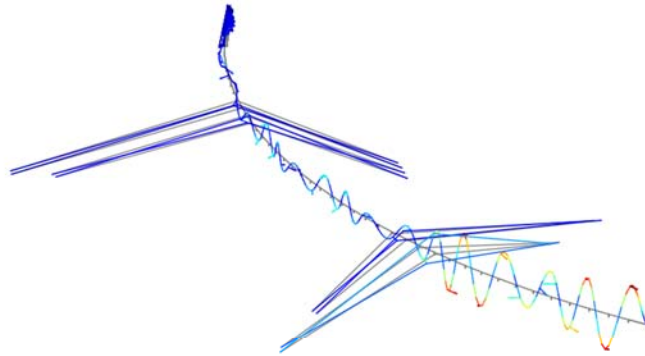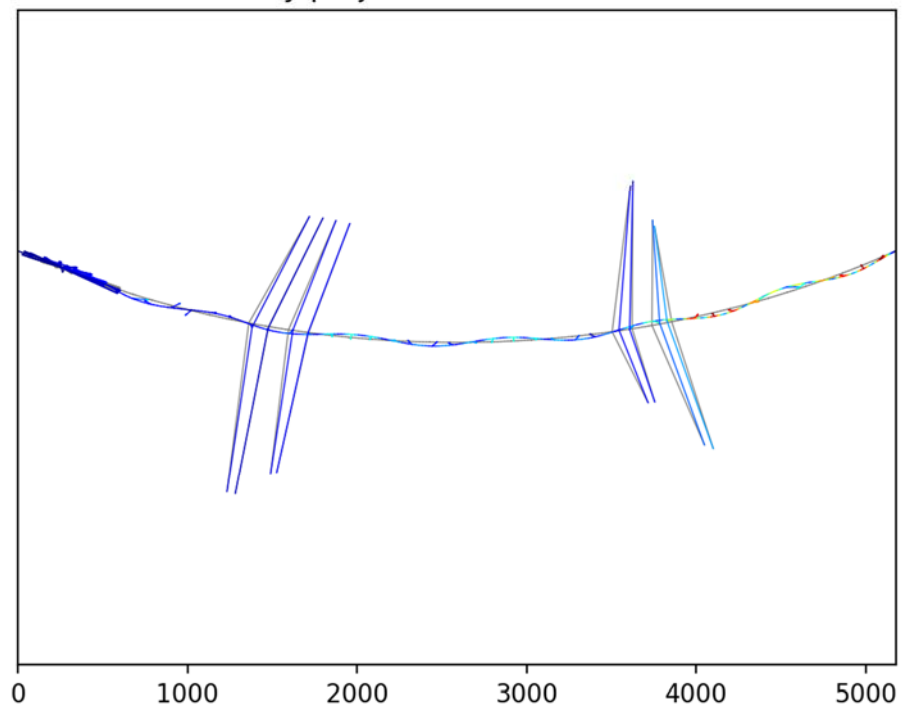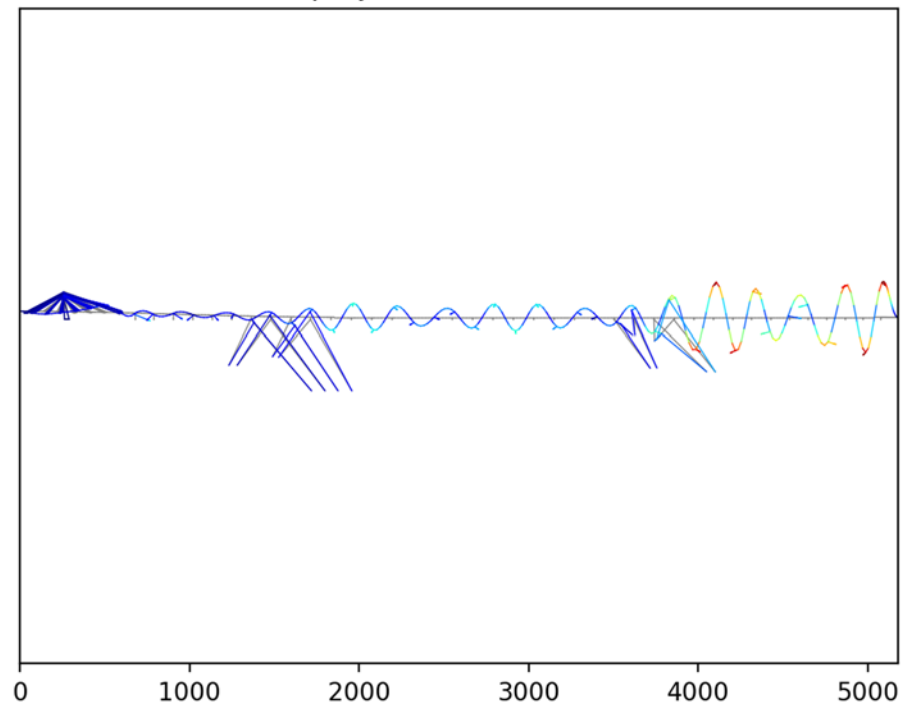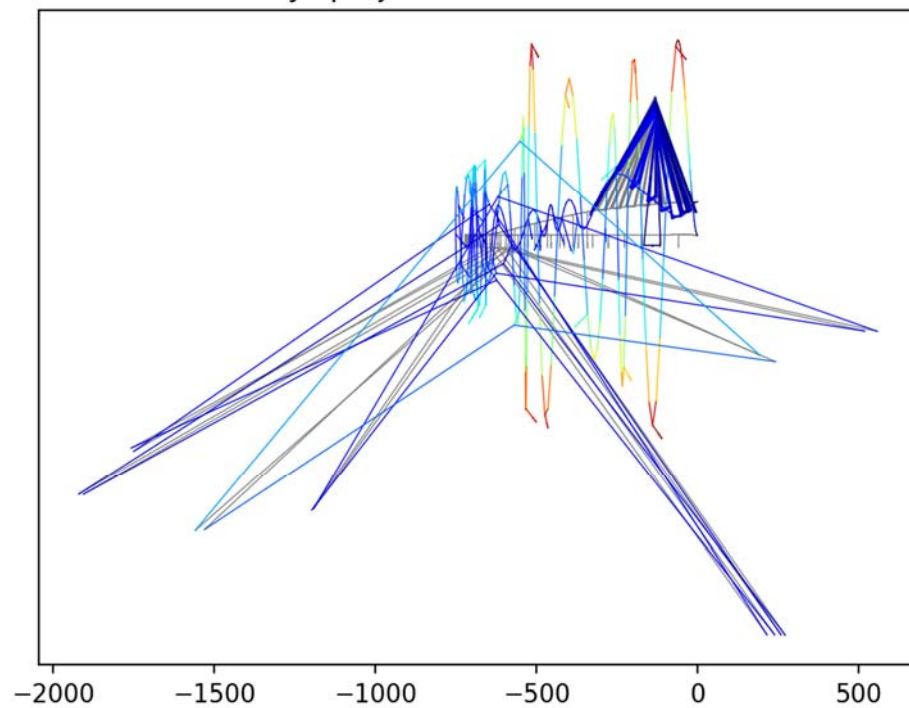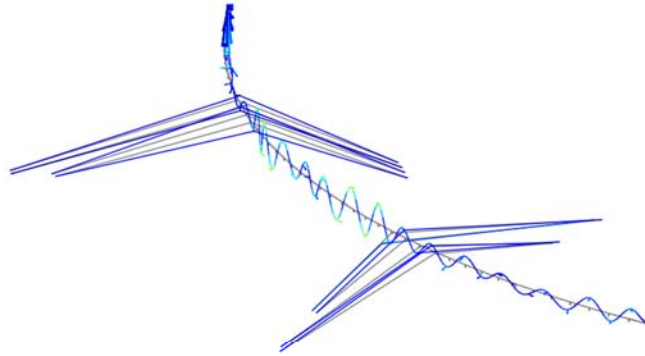

xy projection for mode 58

xz projection for mode 58

yz projection for mode 58

iso projection for mode 59

xy projection for mode 59

xz projection for mode 59

yz projection for mode 59

iso projection for mode 60

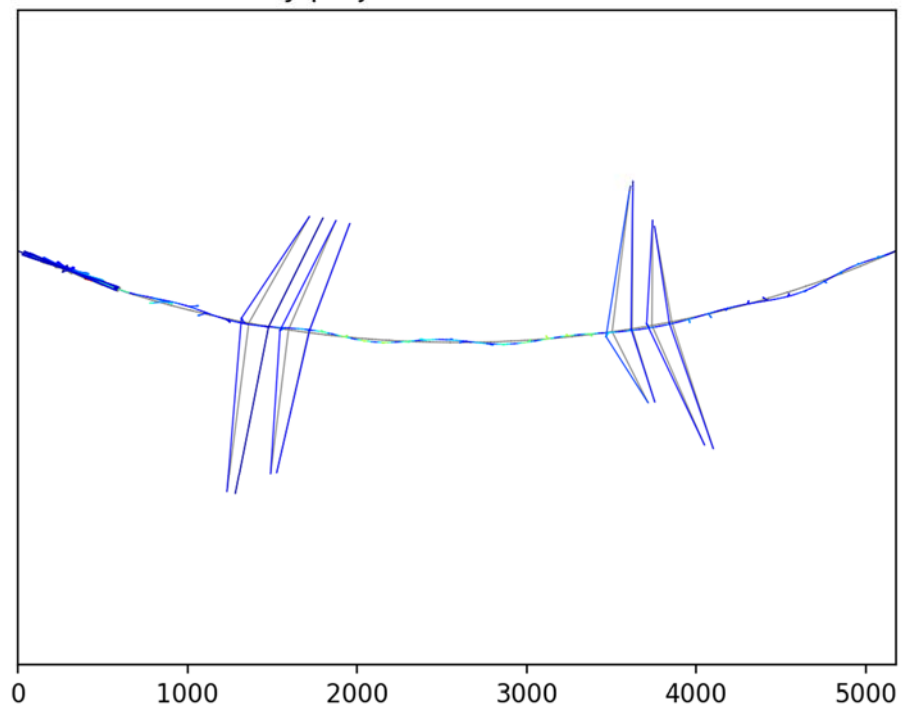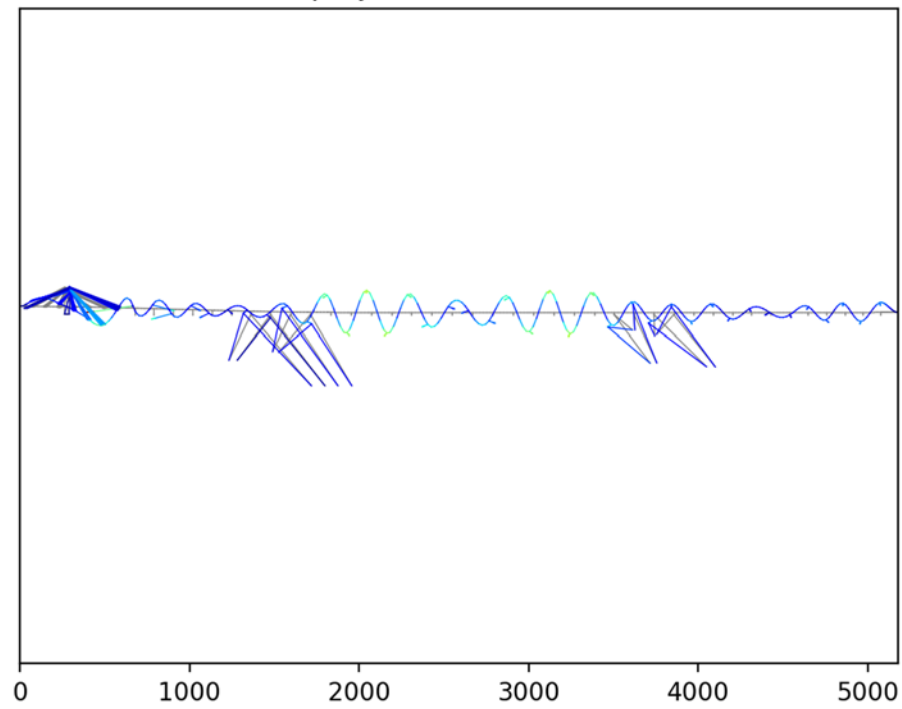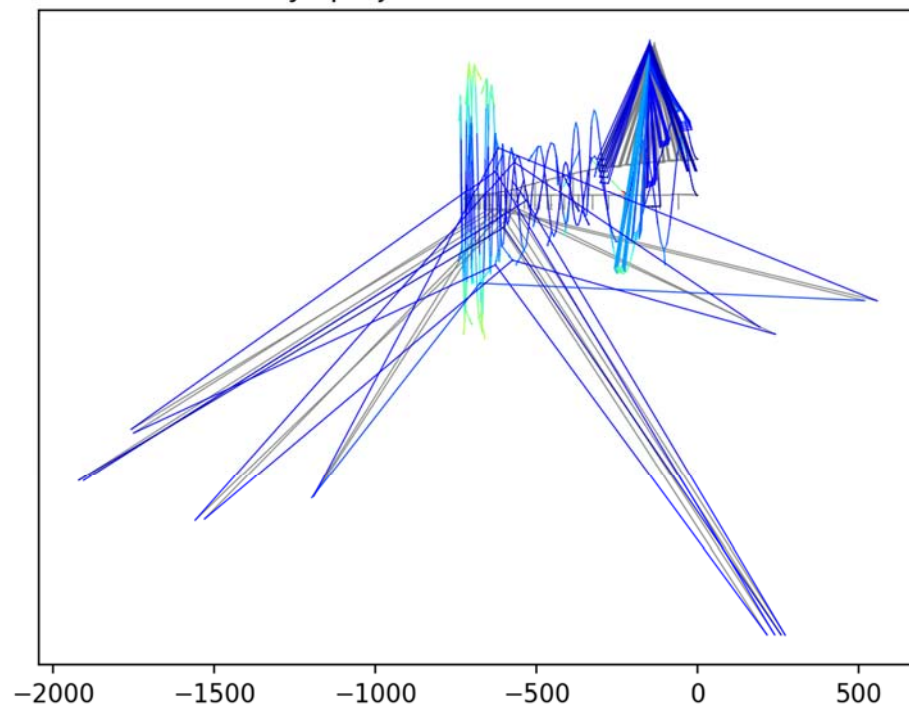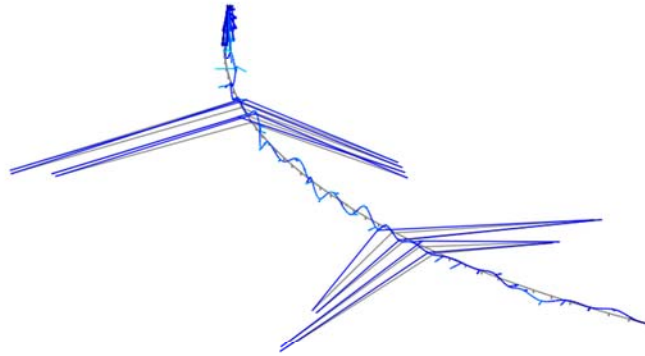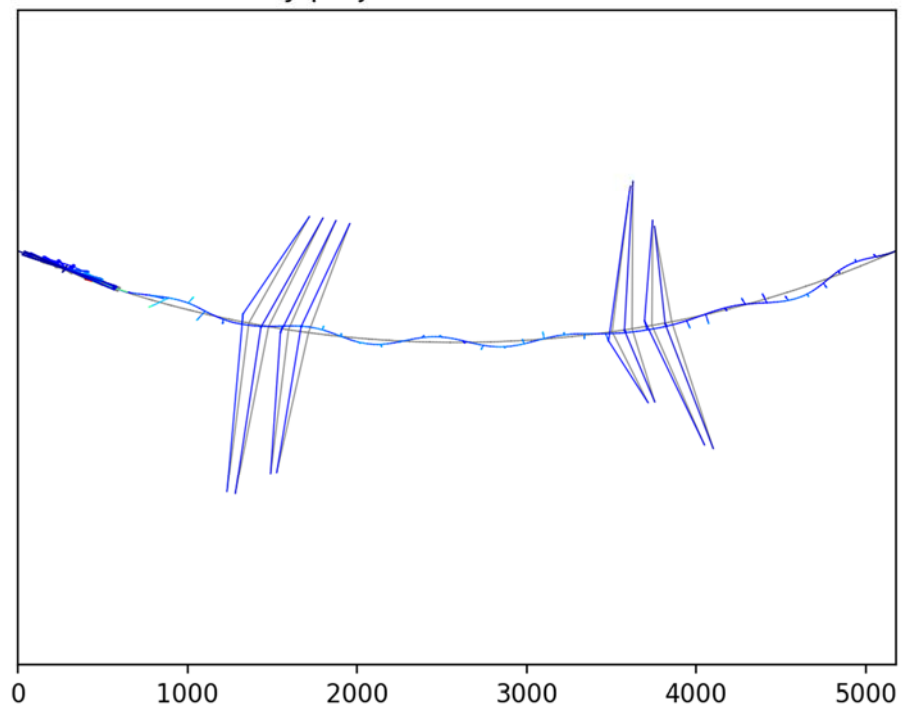xy projection for mode 60

xz projection for mode 60

yz projection for mode 60

iso projection for mode 61

xy projection for mode 61

xz projection for mode 61
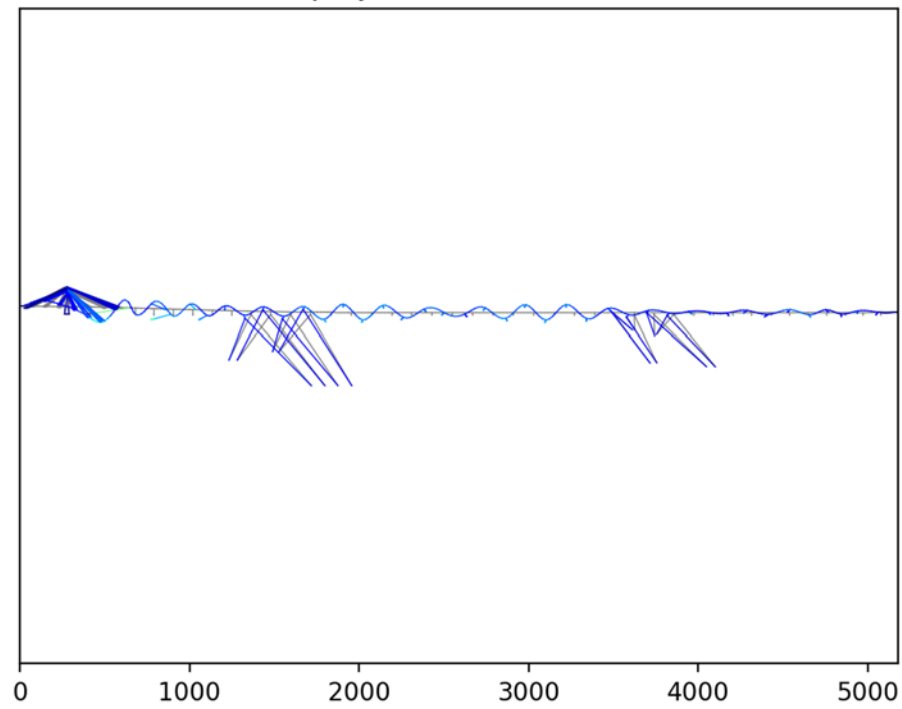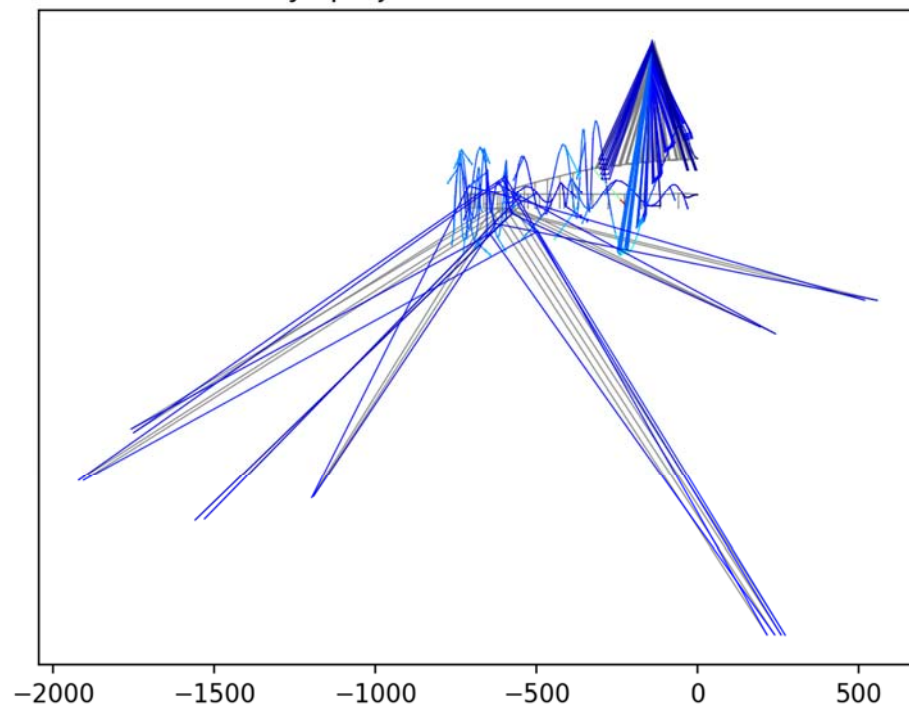

yz projection for mode 61

iso projection for mode 62
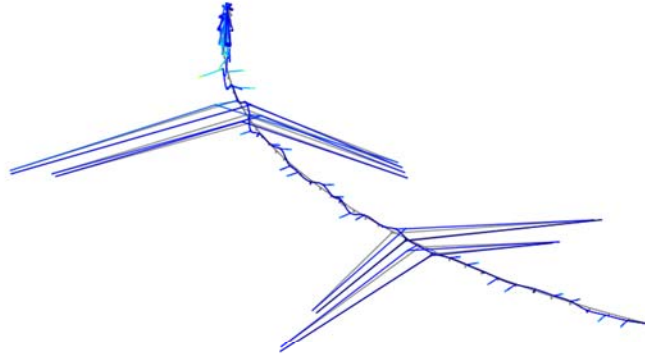

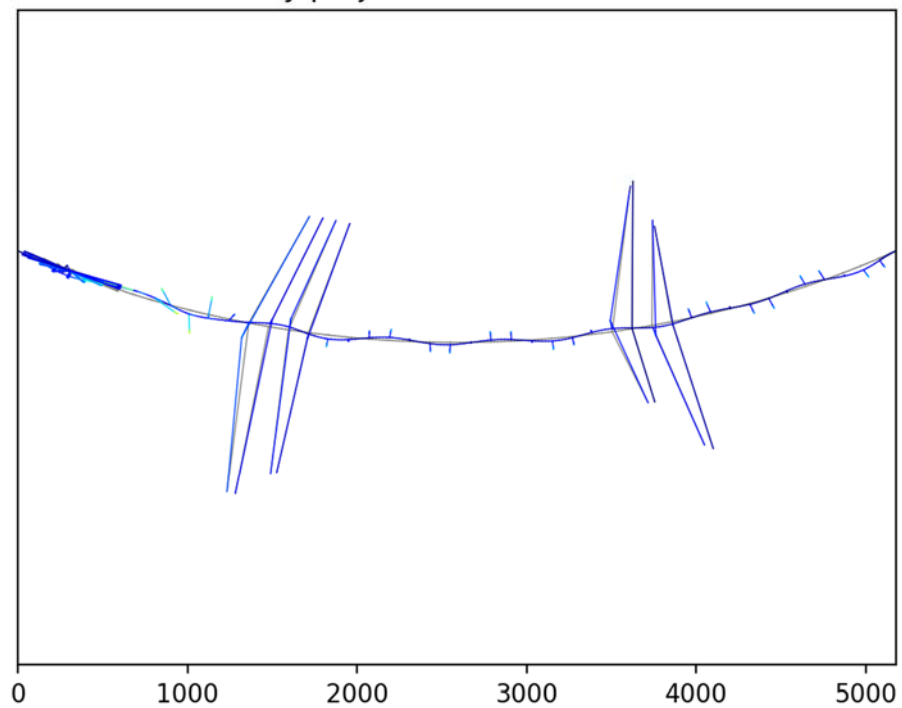xy projection for mode 62

xz projection for mode 62
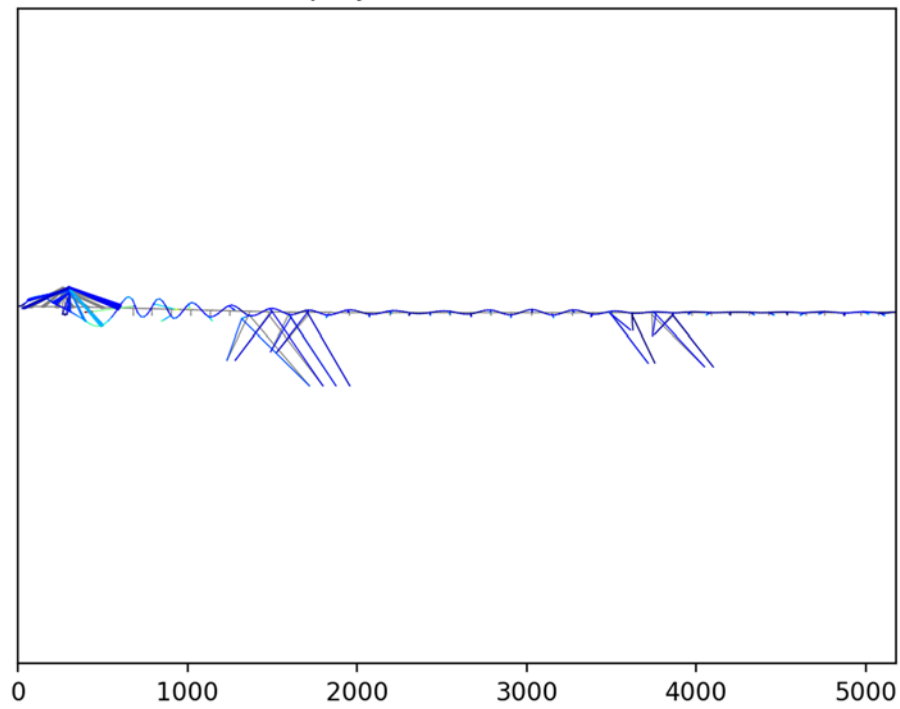

yz projection for mode 62

iso projection for mode 63

xy projection for mode 63
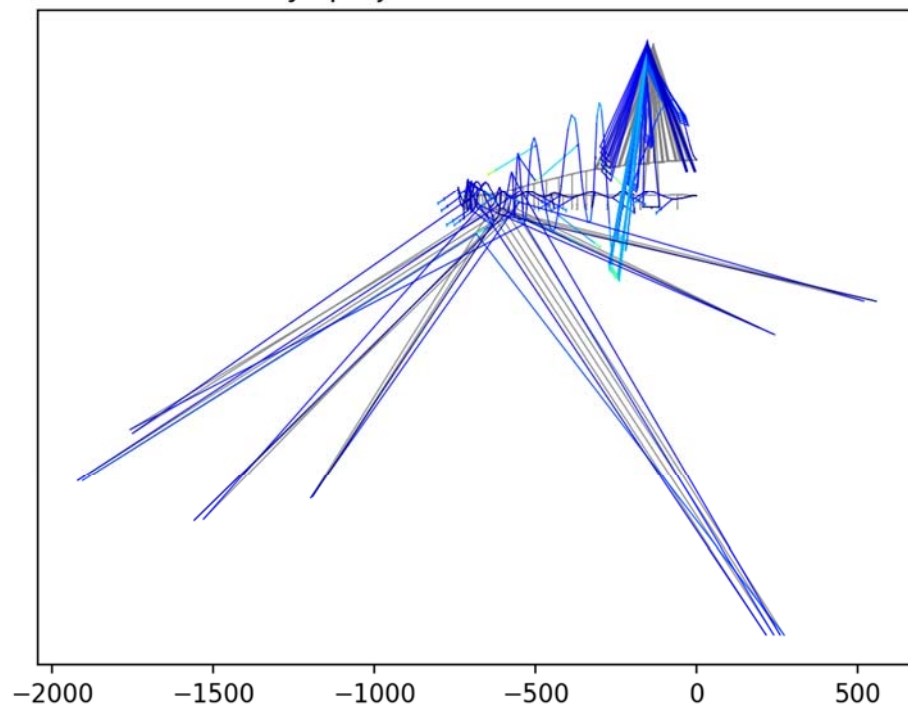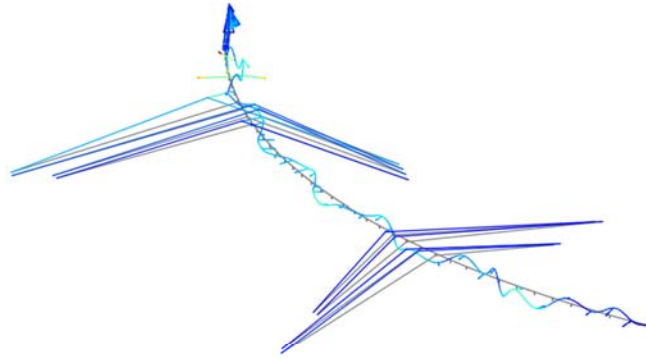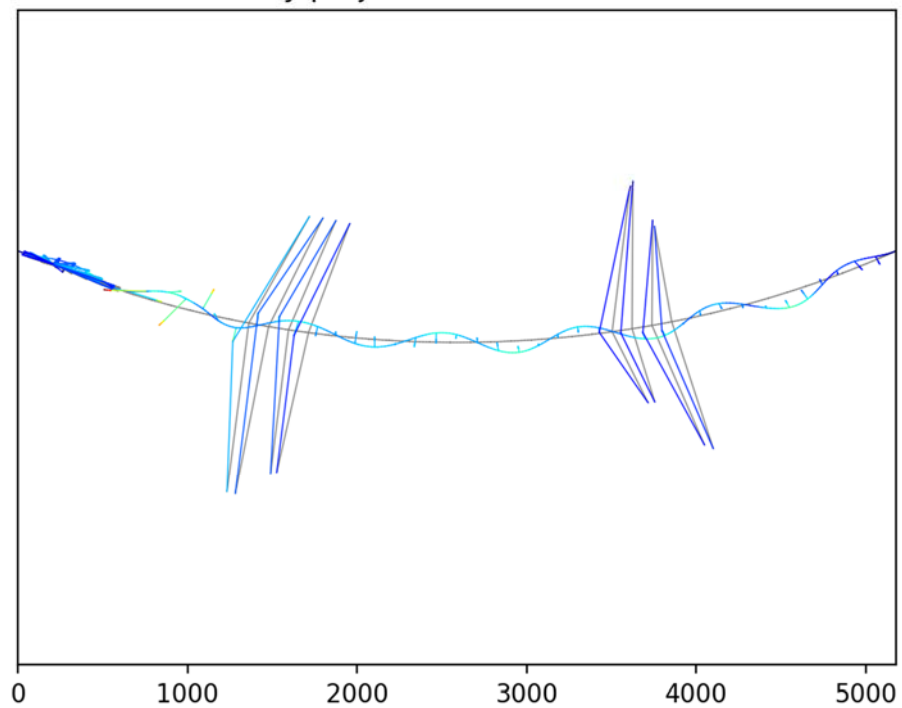
xz projection for mode 63

yz projection for mode 63

iso projection for mode 64

xy projection for mode 64

xz projection for mode 64
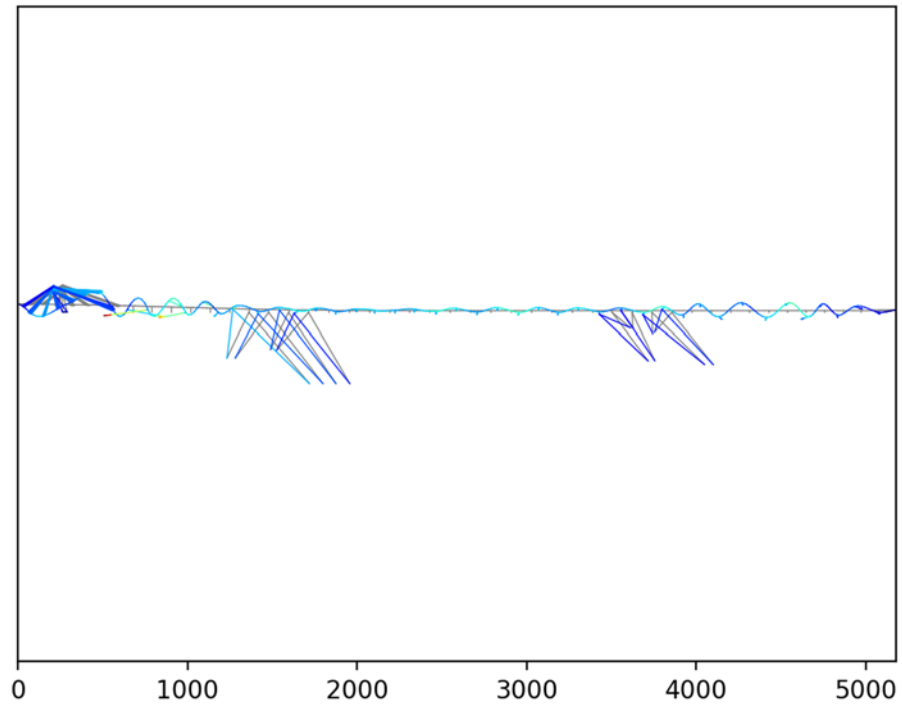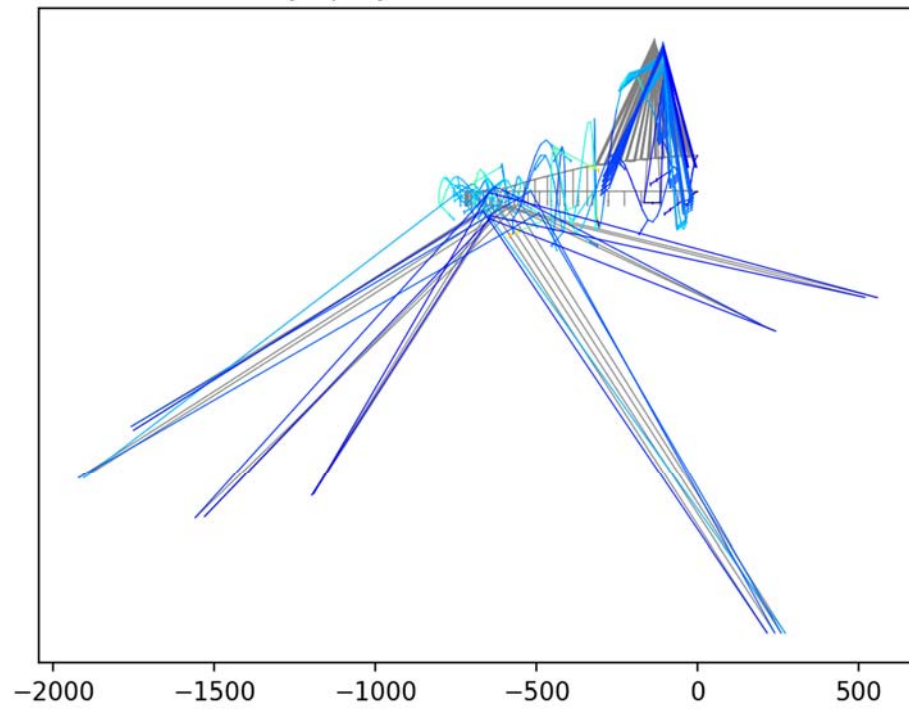

yz projection for mode 64

iso projection for mode 65
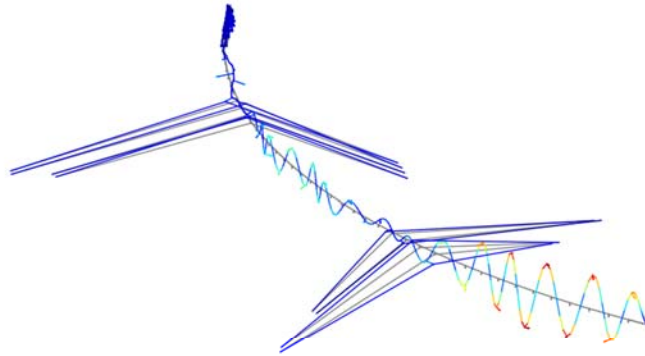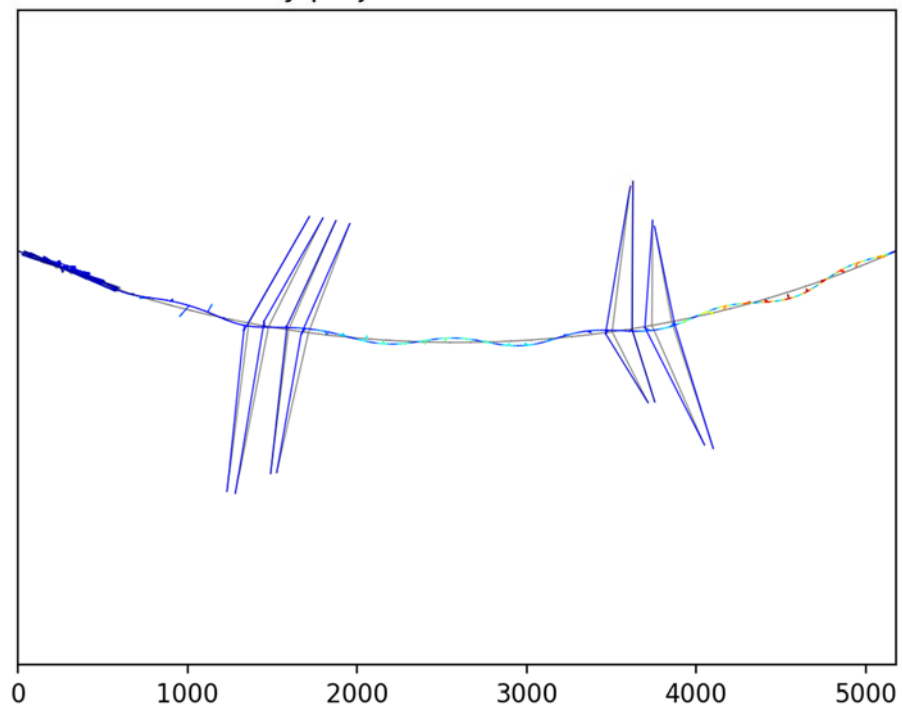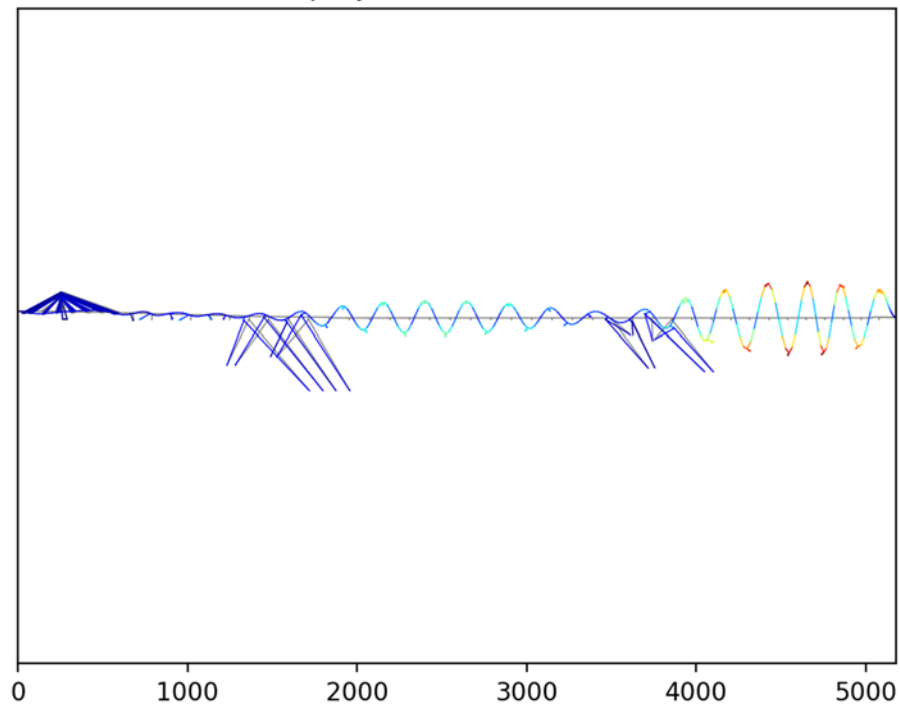

xy projection for mode 65

xz projection for mode 65

yz projection for mode 65

iso projection for mode 66

xy projection for mode 66

xz projection for mode 66
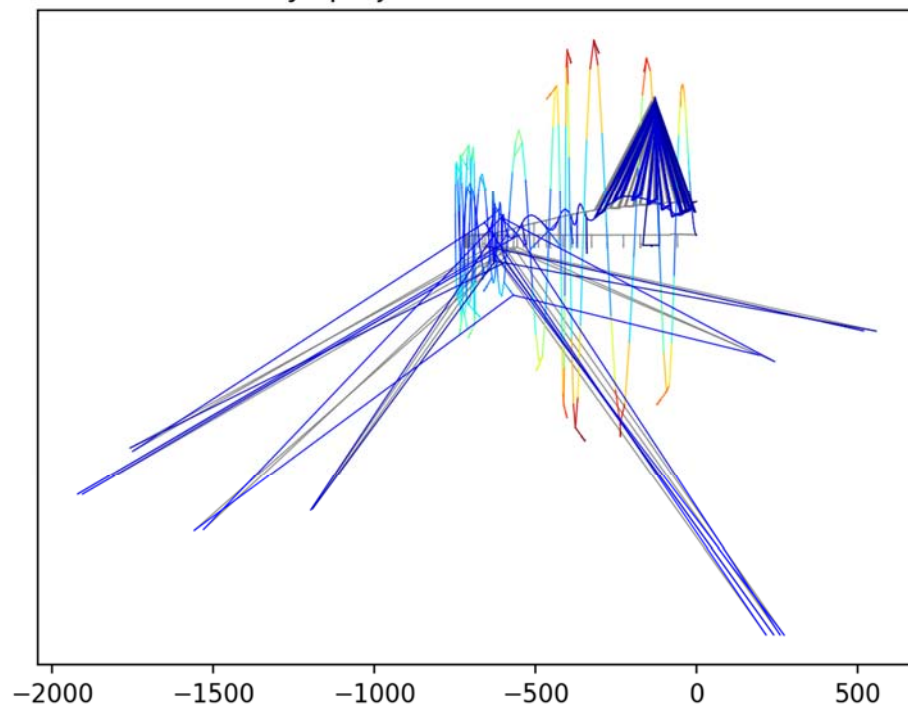

yz projection for mode 66

iso projection for mode 67
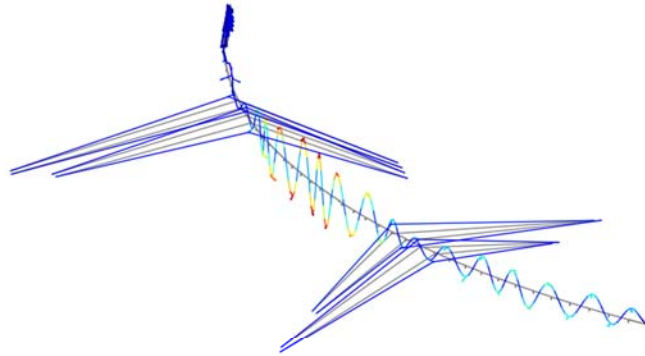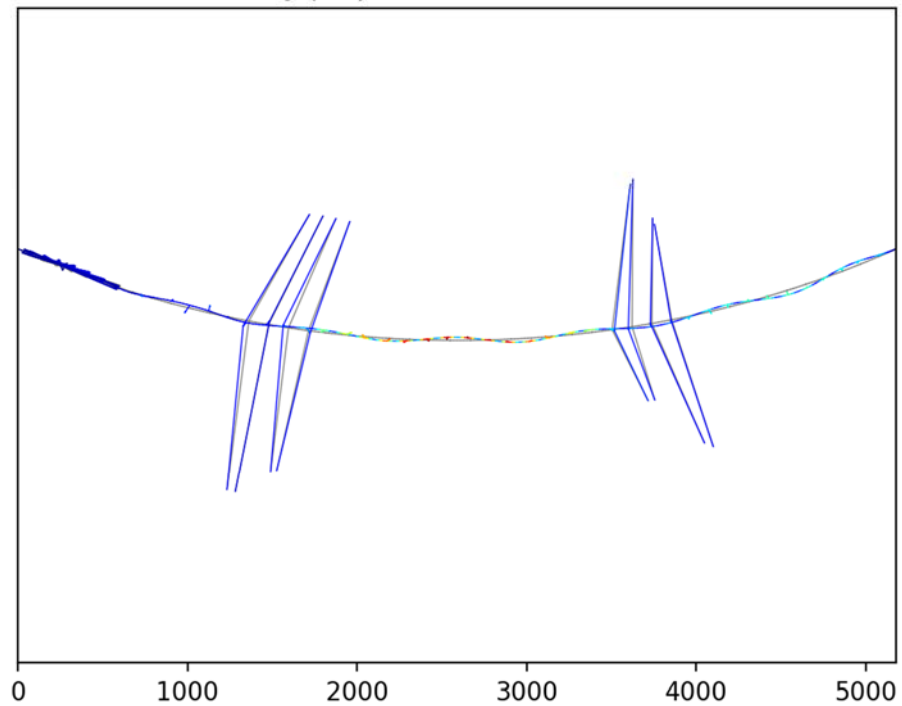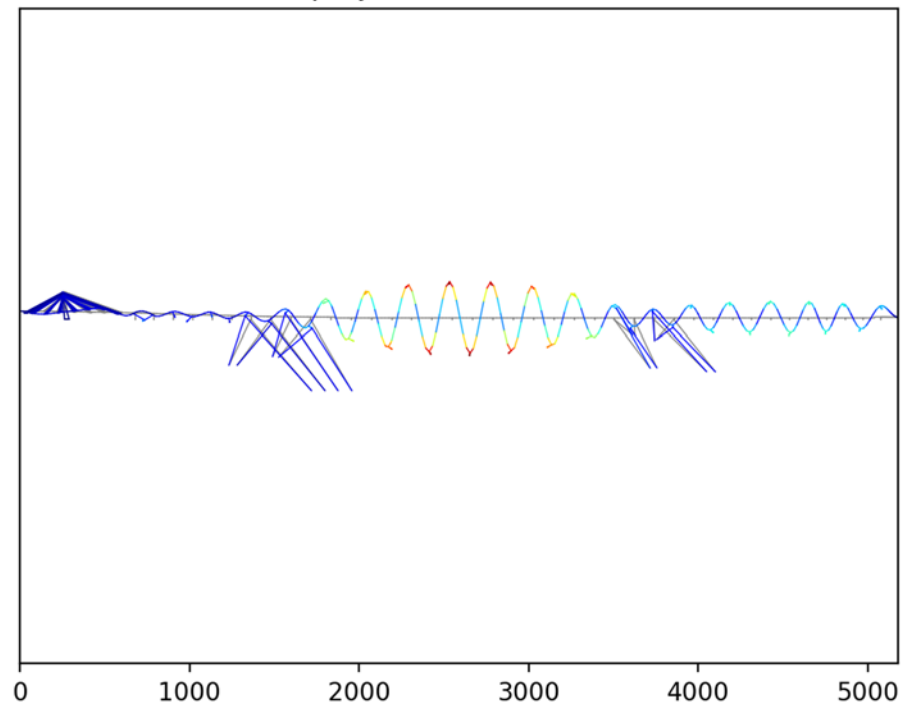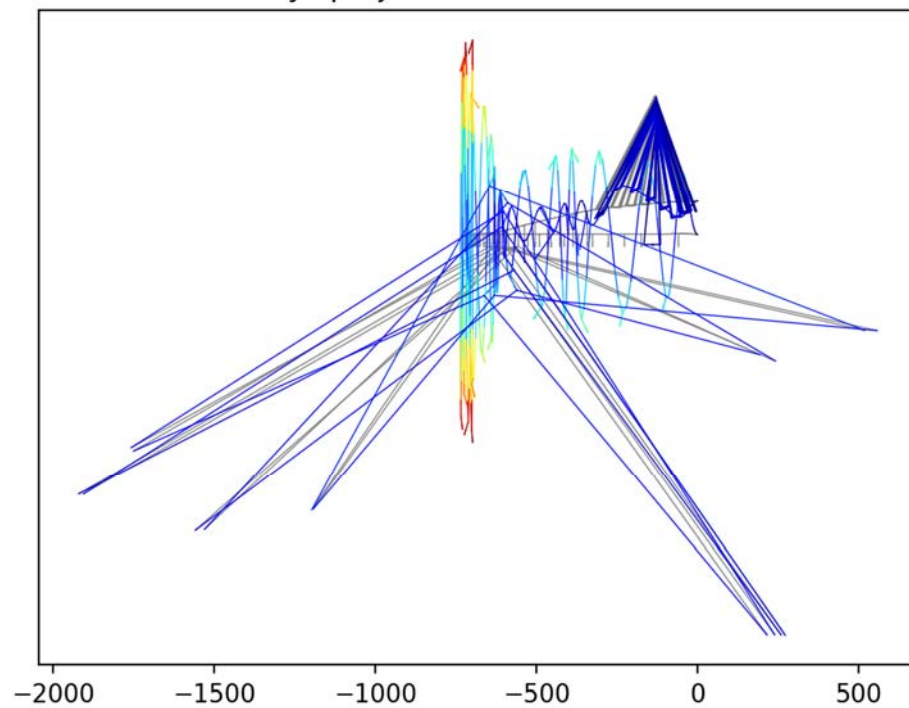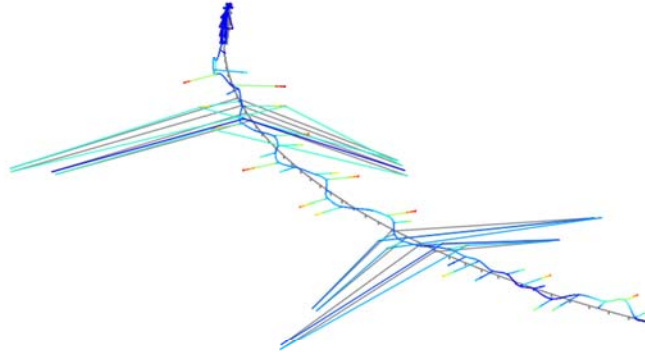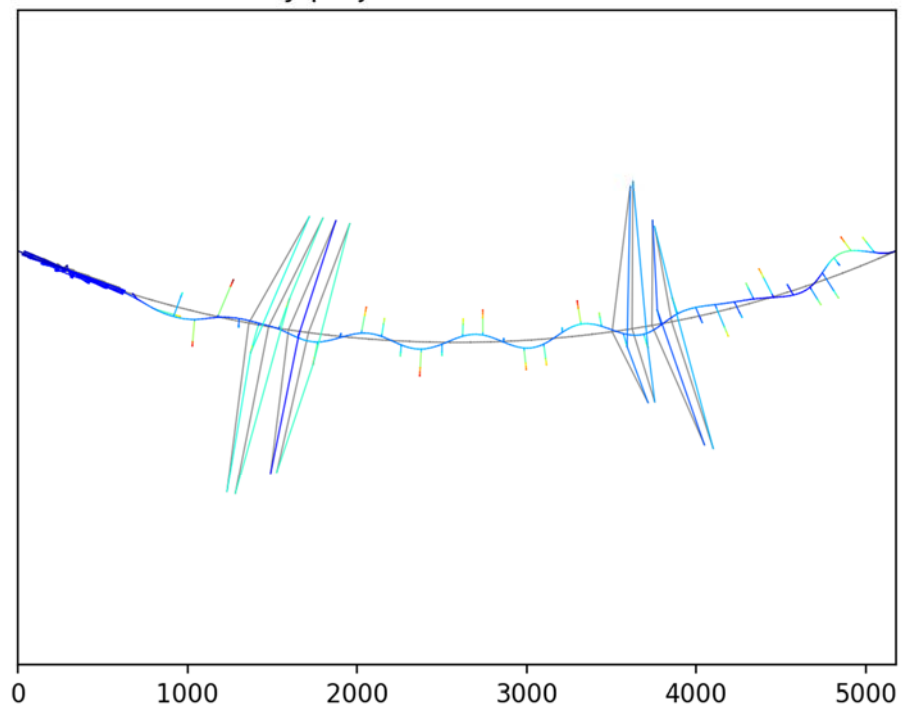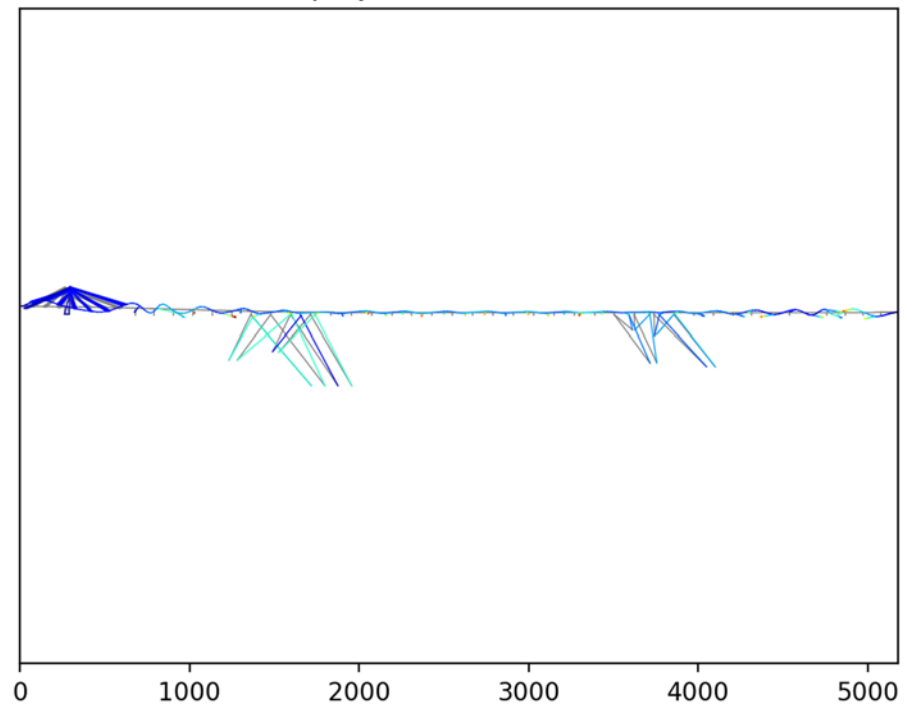

xy projection for mode 67

xz projection for mode 67

yz projection for mode 67

iso projection for mode 68

xy projection for mode 68

xz projection for mode 68

yz projection for mode 68

iso projection for mode 69

xy projection for mode 69

xz projection for mode 69
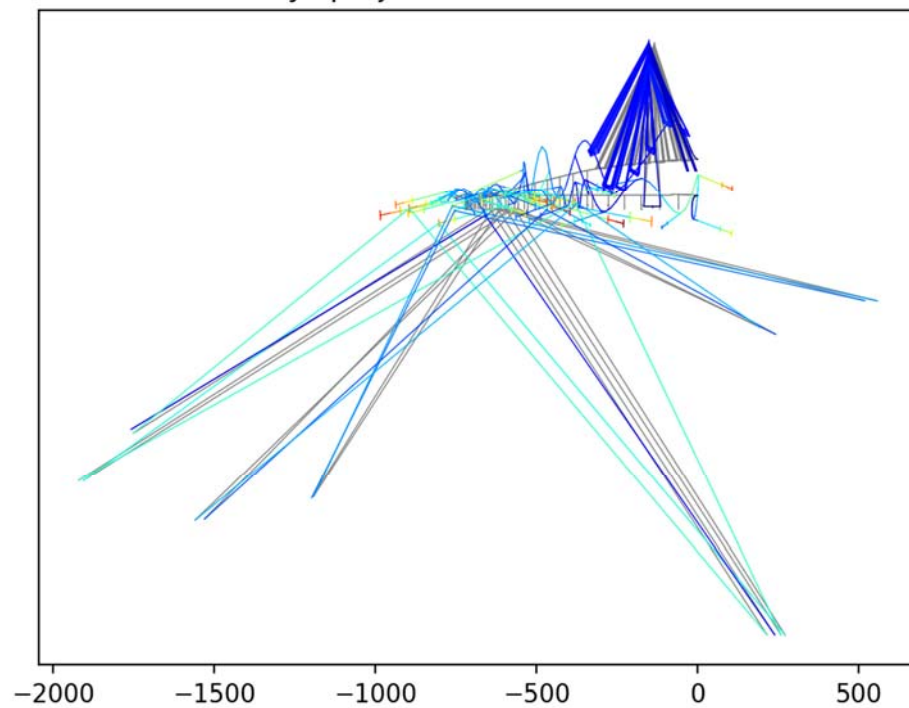

yz projection for mode 69

iso projection for mode 70
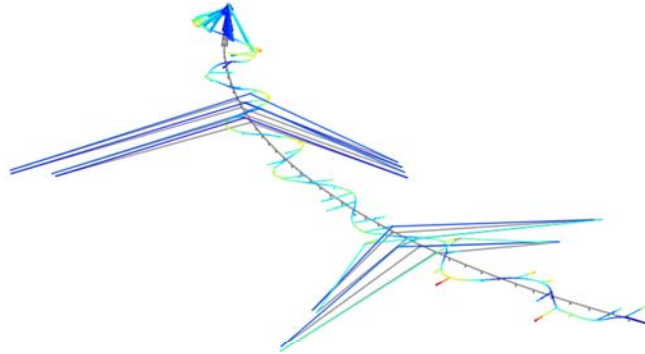

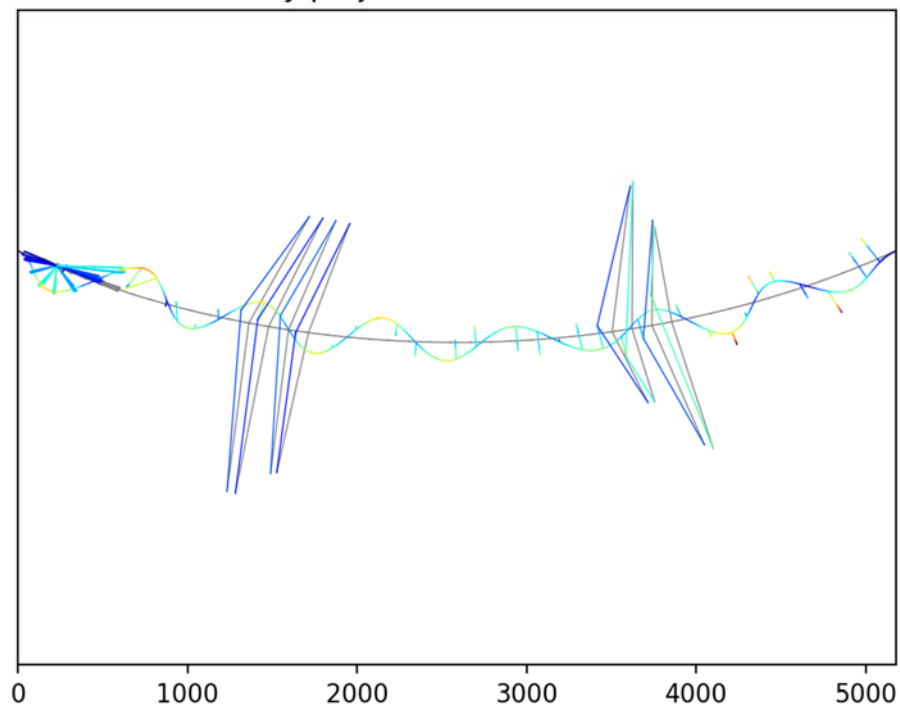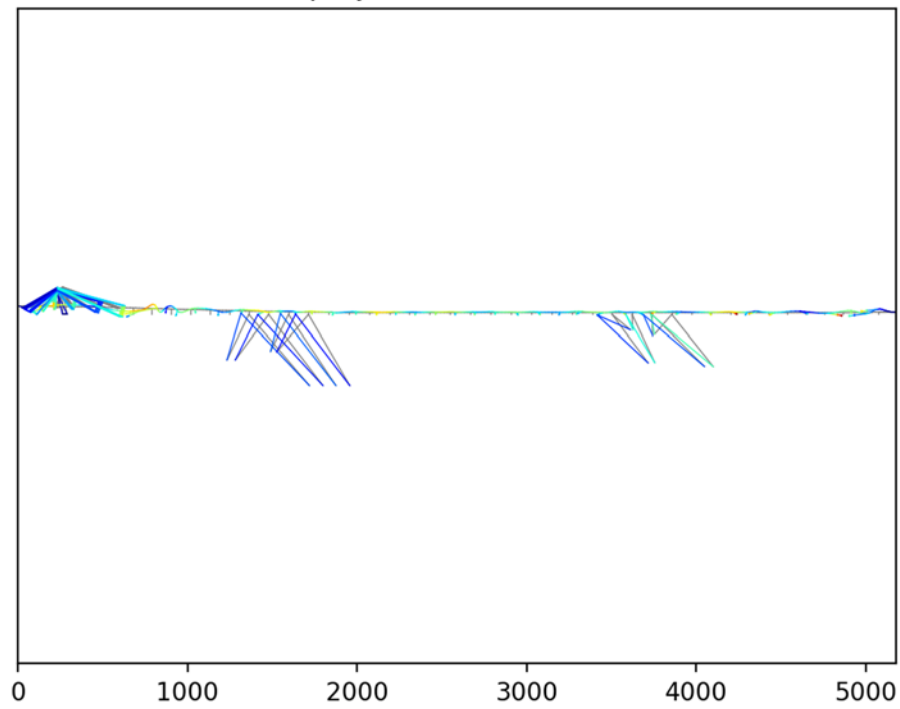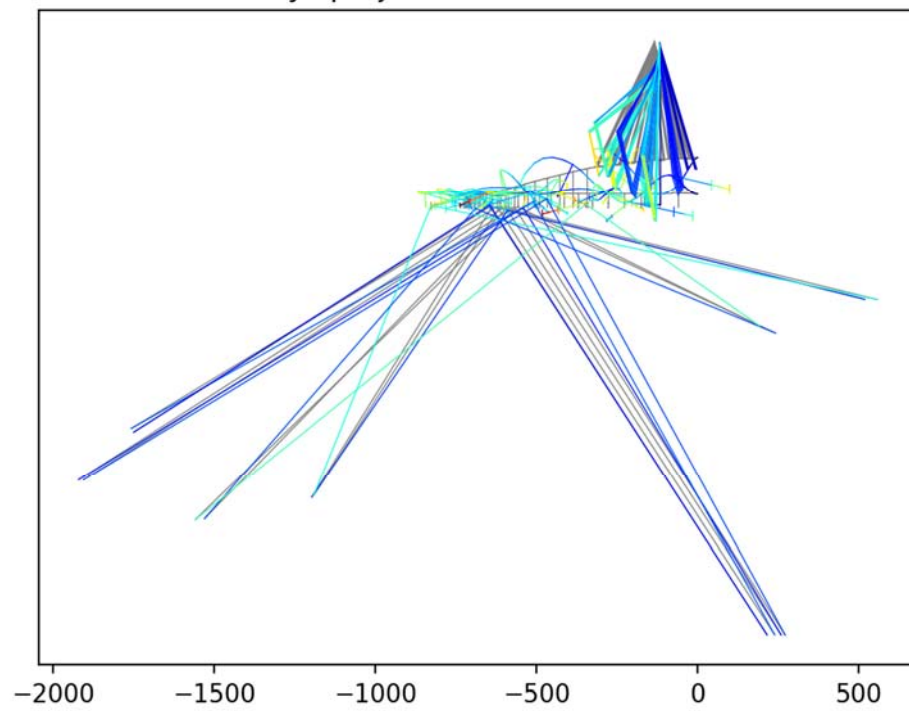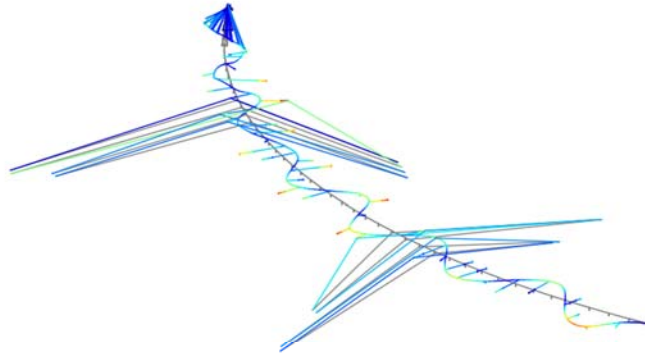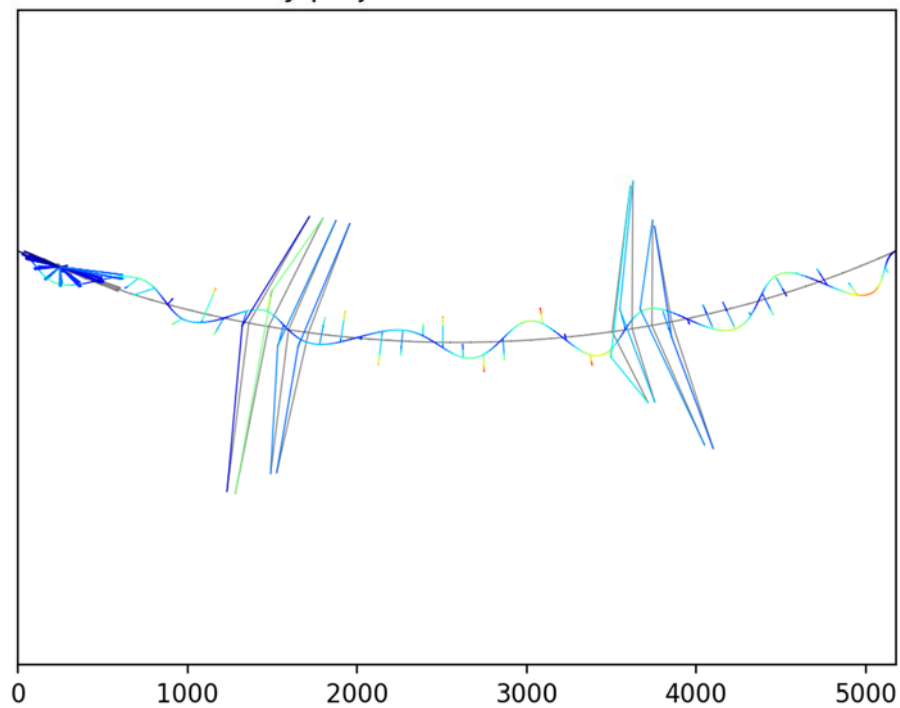xy projection for mode 70

xz projection for mode 70

yz projection for mode 70

iso projection for mode 71

xy projection for mode 71

xz projection for mode 71
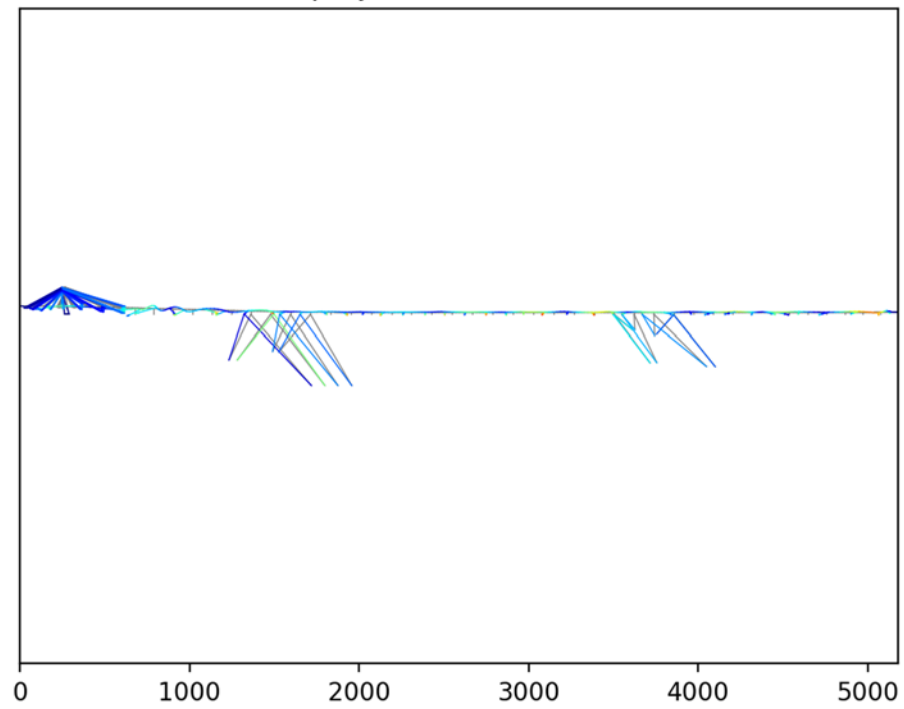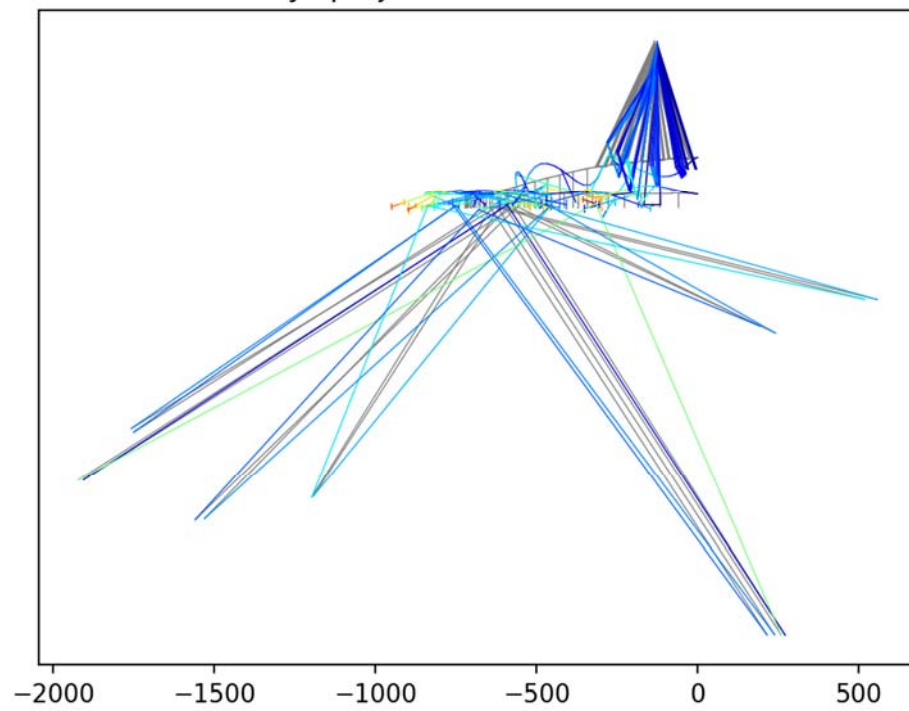

yz projection for mode 71

iso projection for mode 72
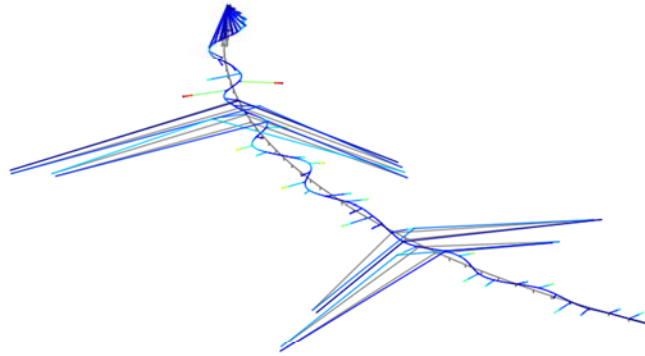

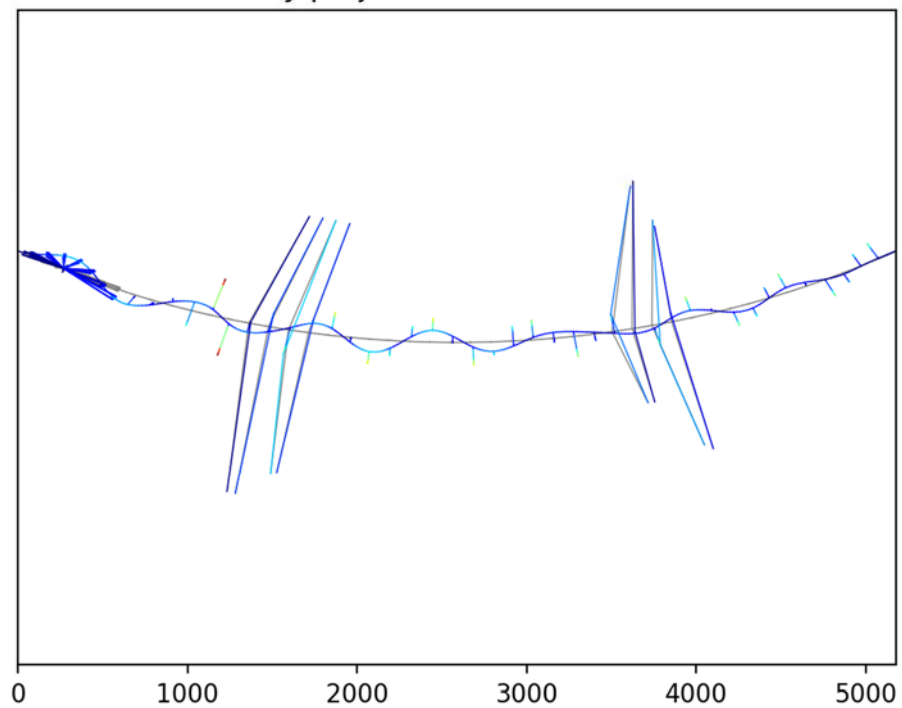xy projection for mode 72

xz projection for mode 72
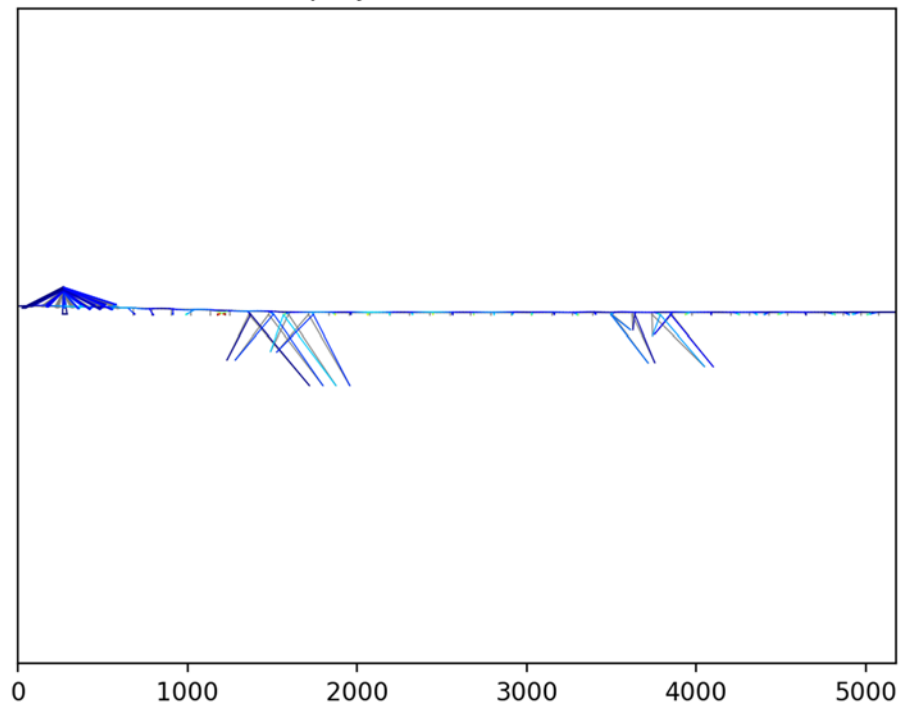

yz projection for mode 72

iso projection for mode 73

xy projection for mode 73
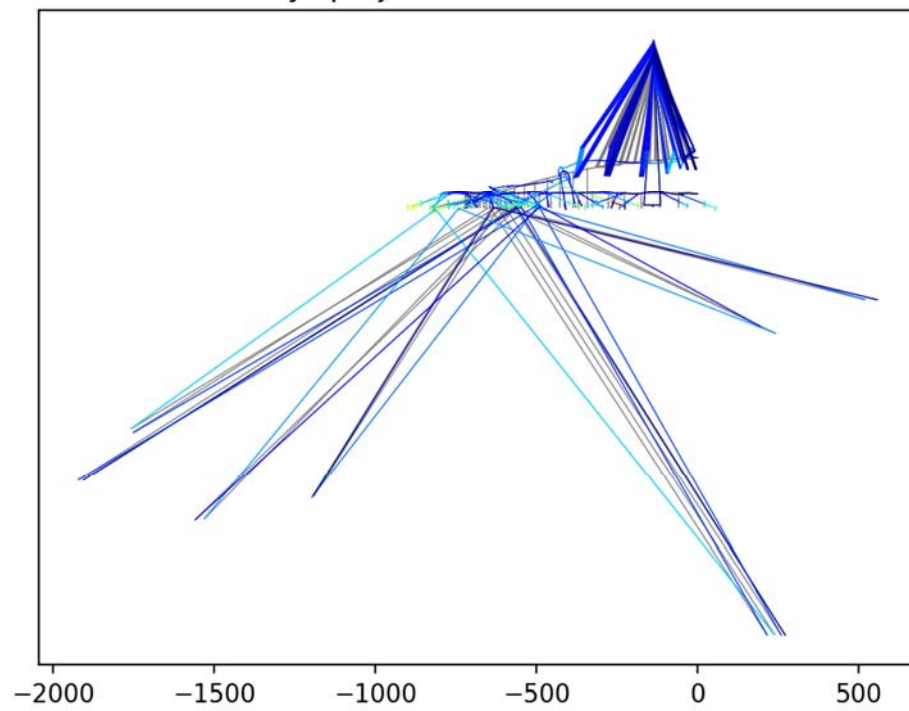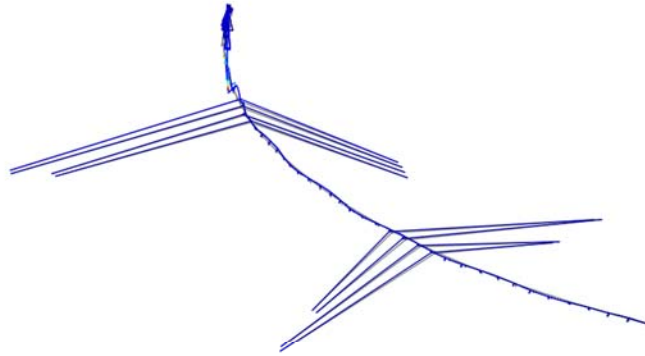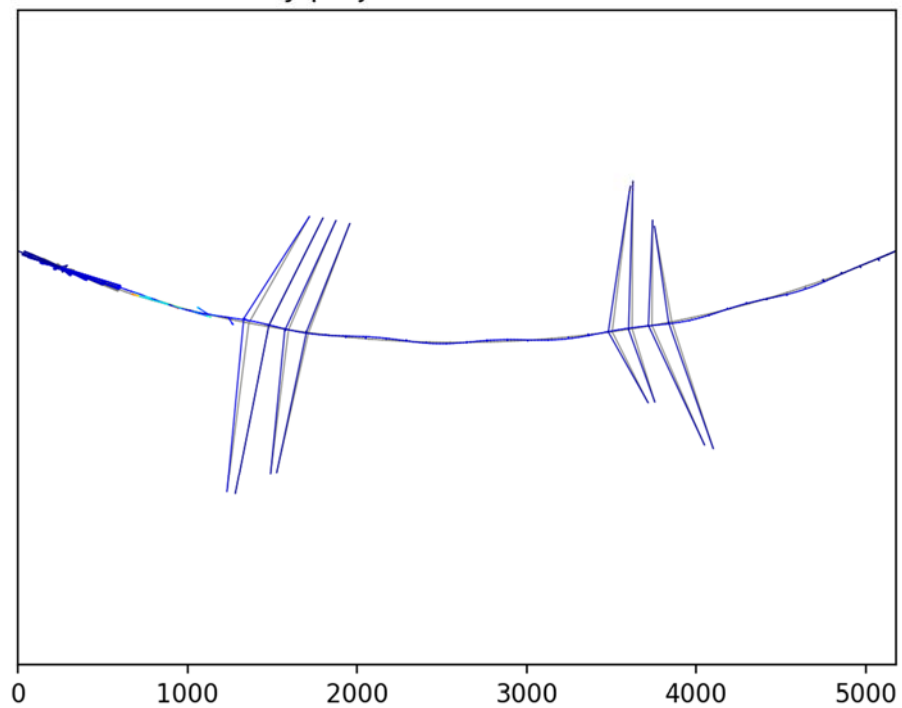
xz projection for mode 73

yz projection for mode 73

iso projection for mode 74

xy projection for mode 74

xz projection for mode 74
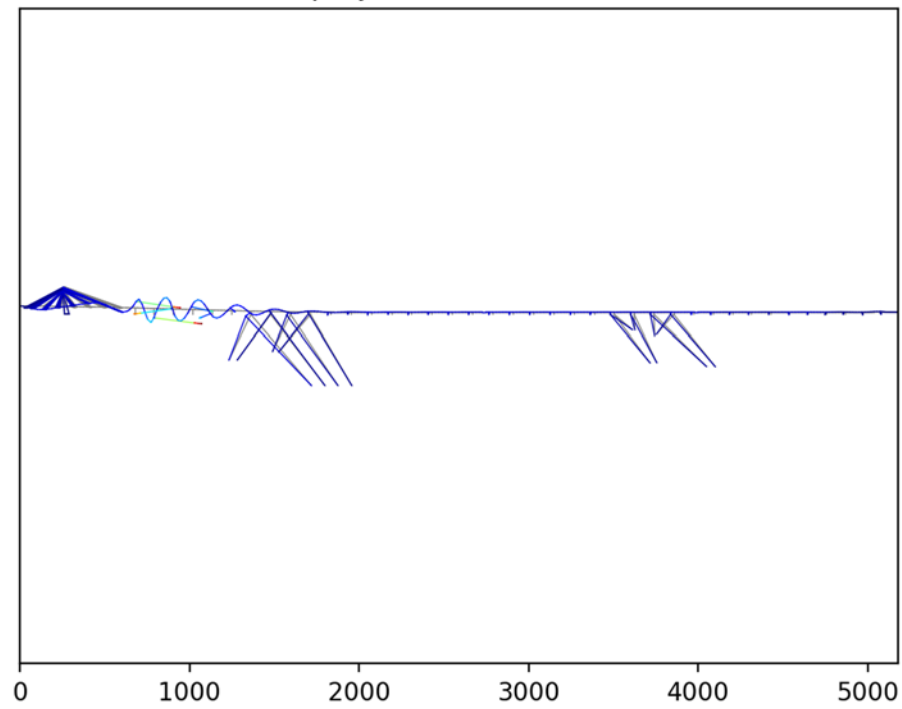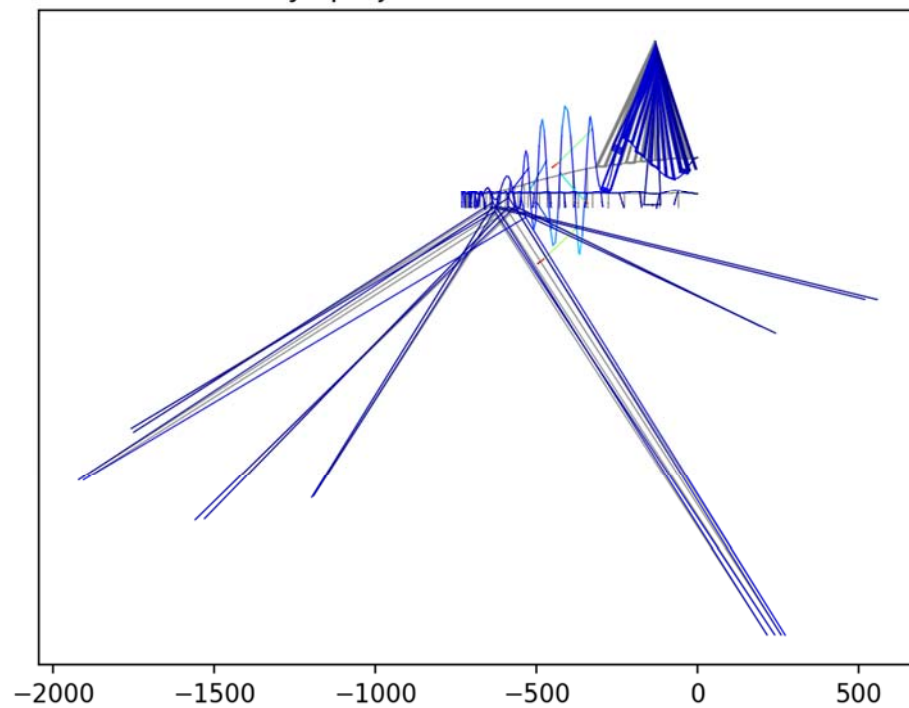

yz projection for mode 74

iso projection for mode 75
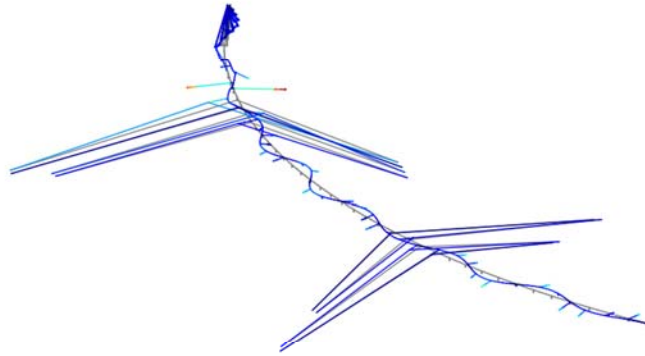

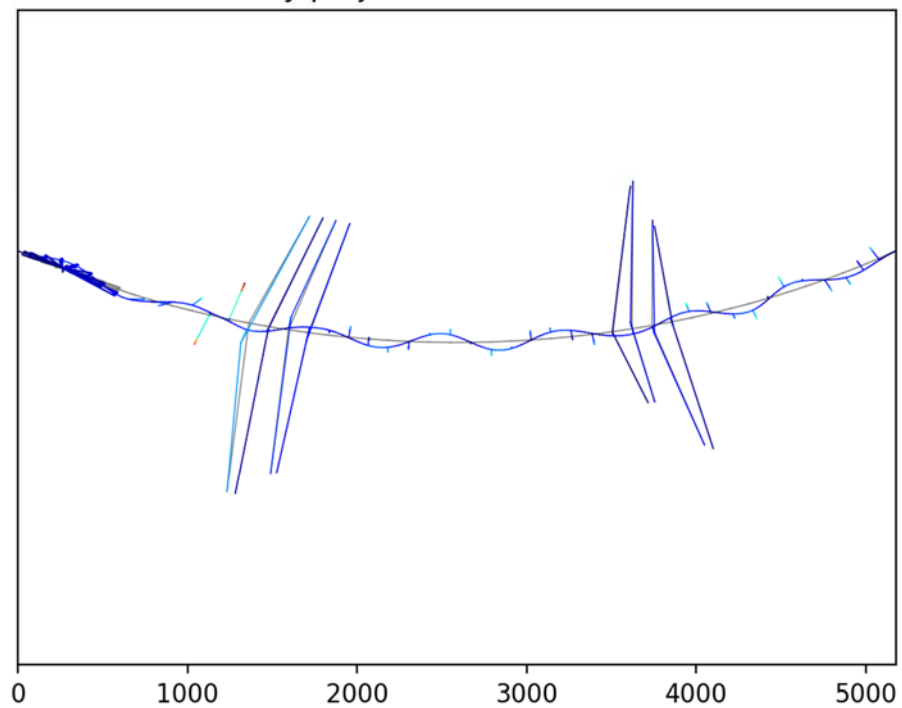xy projection for mode 75

xz projection for mode 75
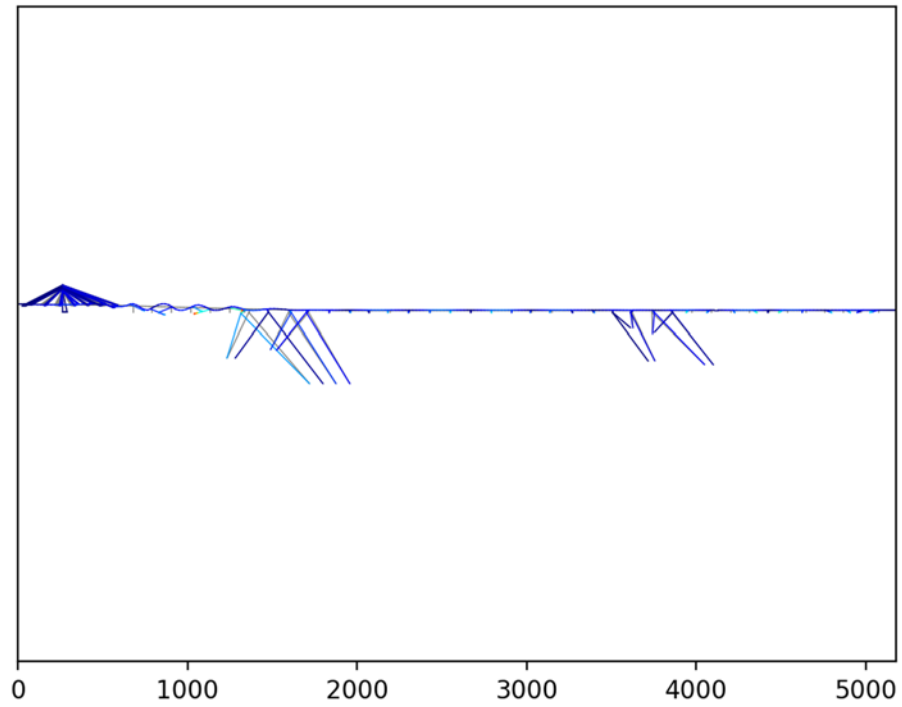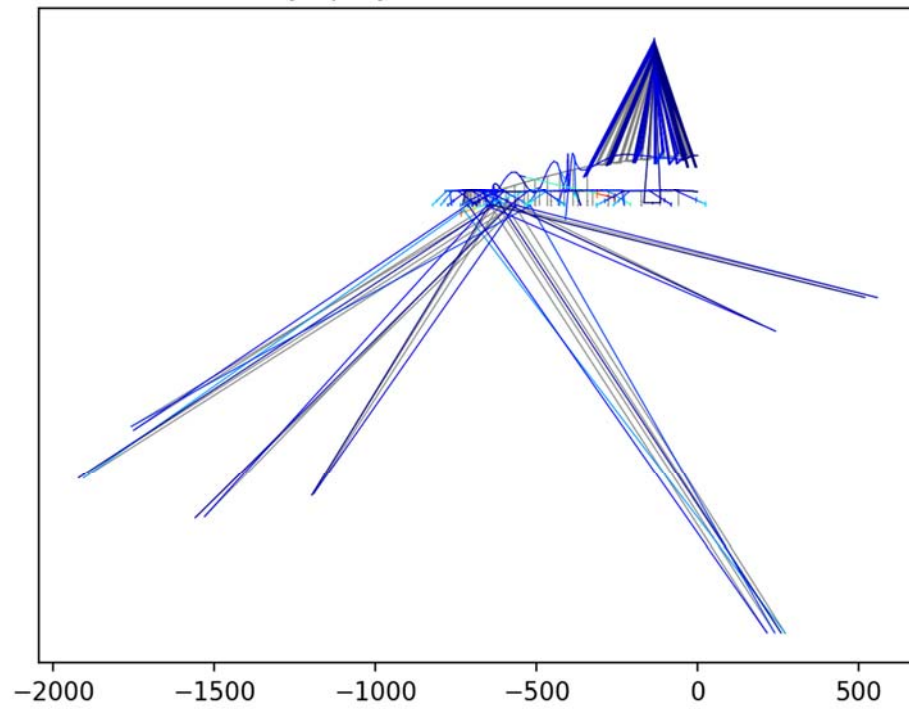

yz projection for mode 75

iso projection for mode 76
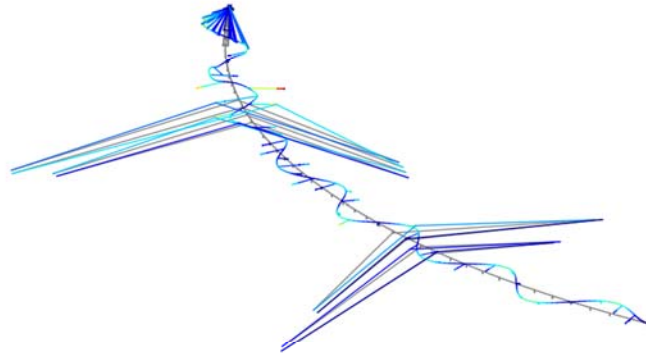

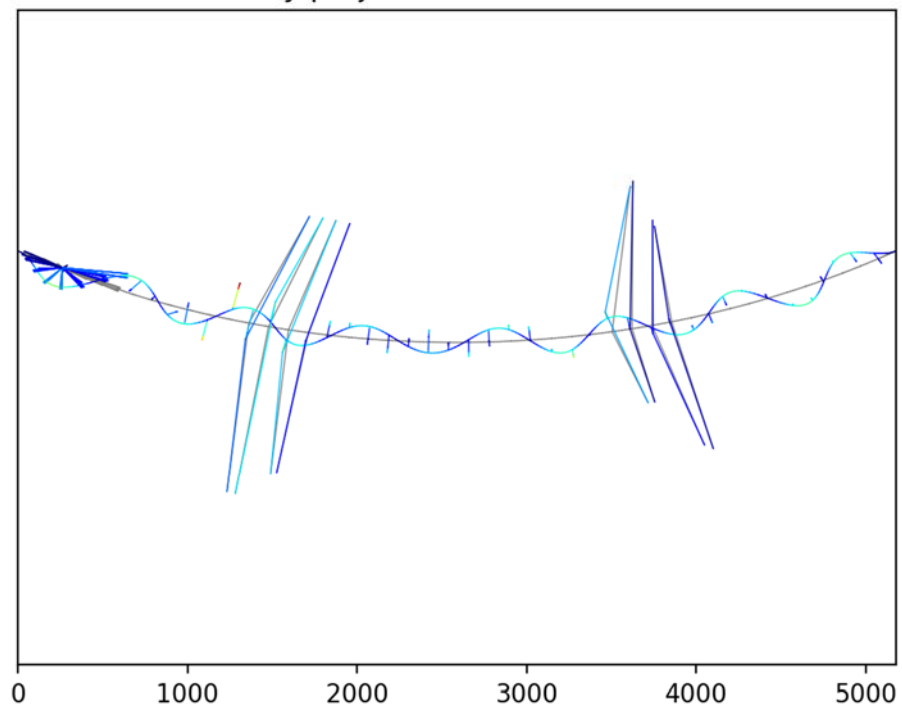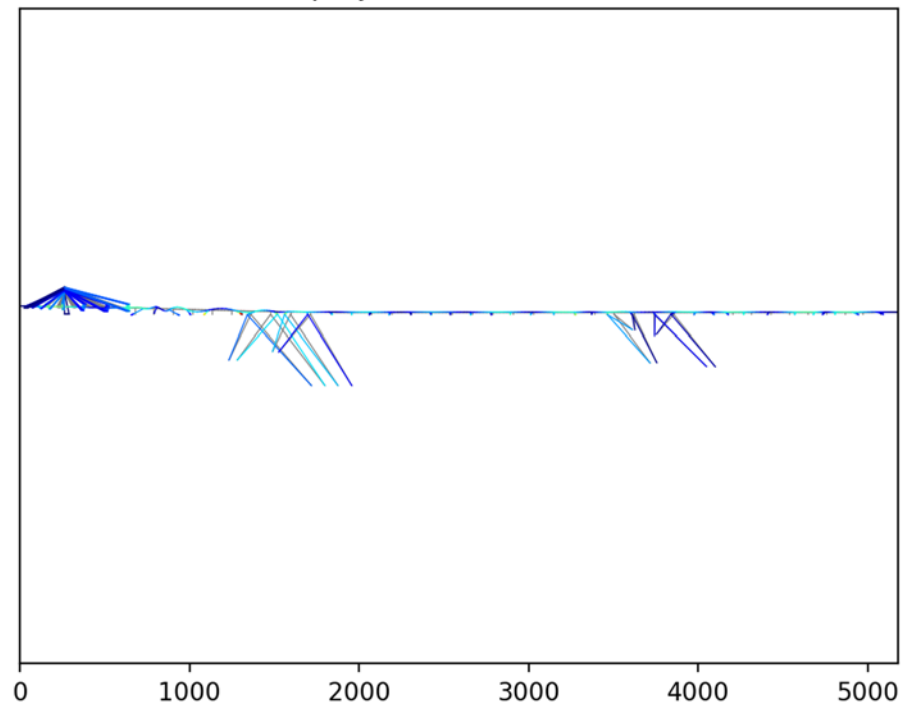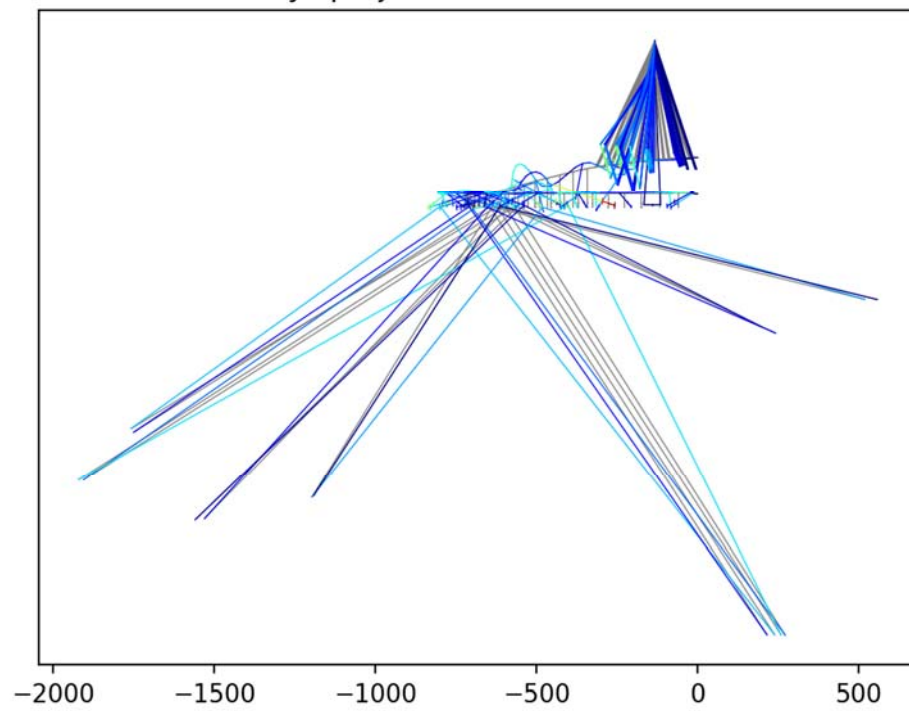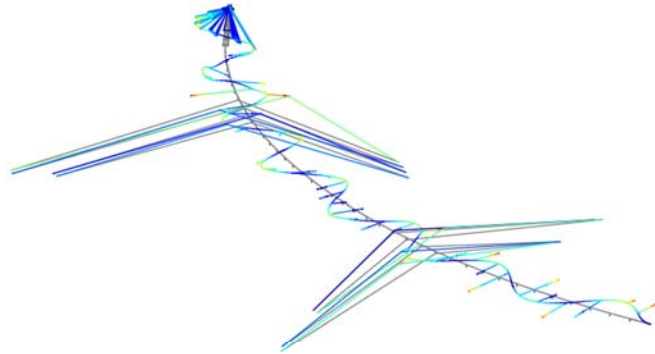xy projection for mode 76

xz projection for mode 76

yz projection for mode 76

iso projection for mode 77

xy projection for mode 77
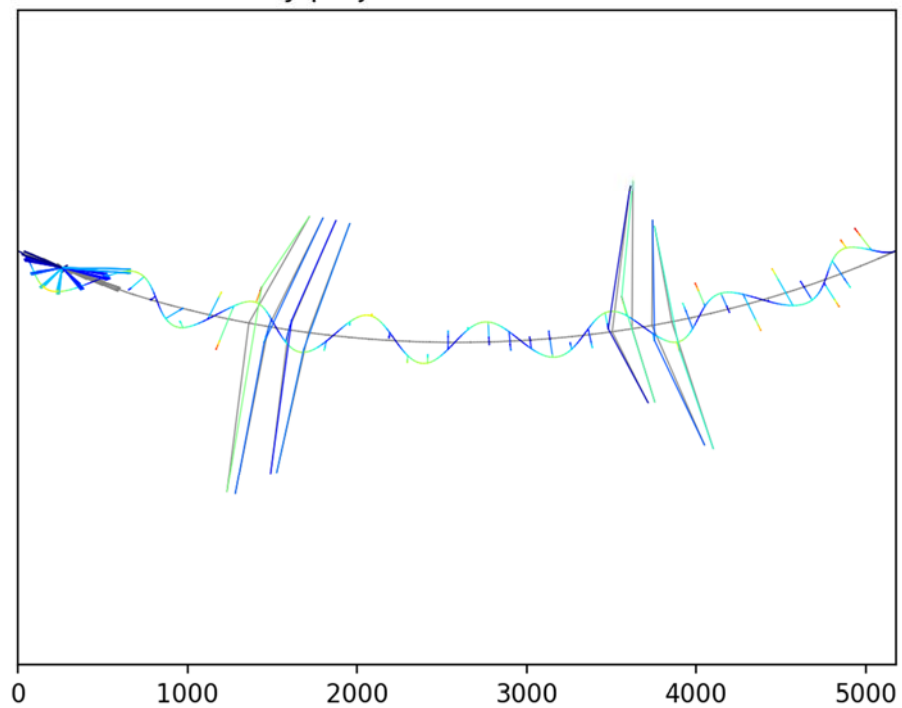
xz projection for mode 77
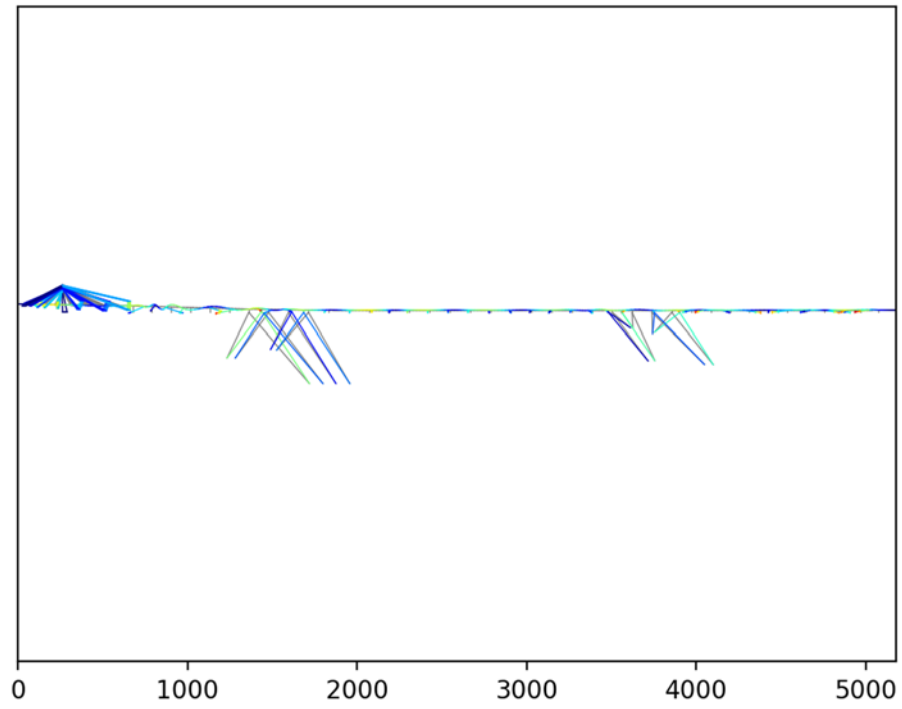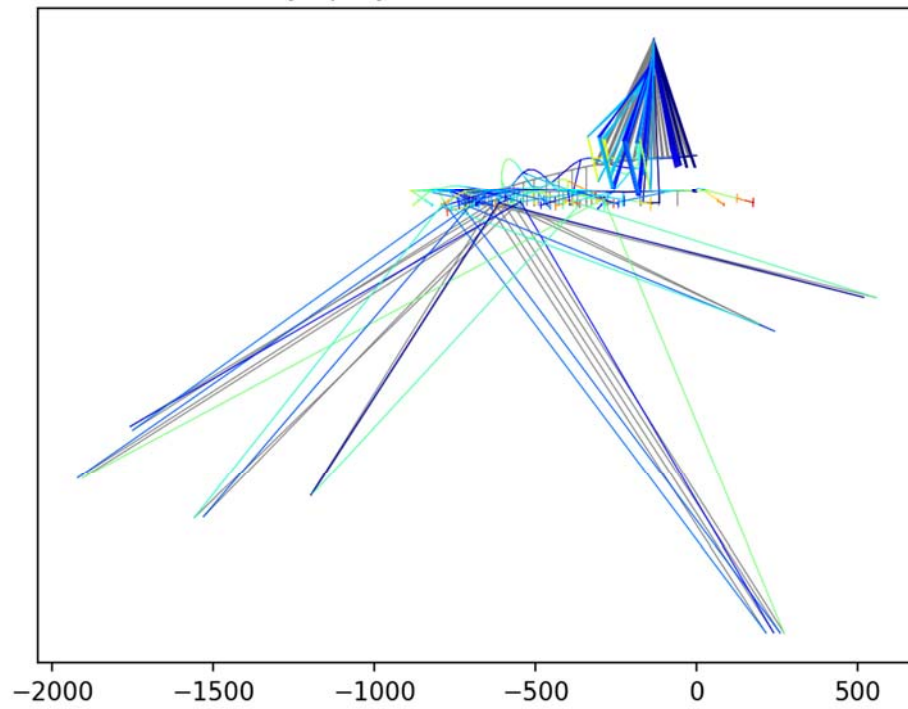

yz projection for mode 77

iso projection for mode 78
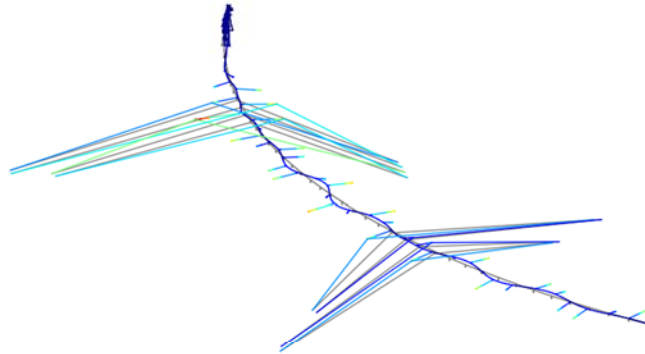

xy projection for mode 78

xz projection for mode 78

yz projection for mode 78

iso projection for mode 79

xy projection for mode 79

xz projection for mode 79

yz projection for mode 79

iso projection for mode 80

xy projection for mode 80
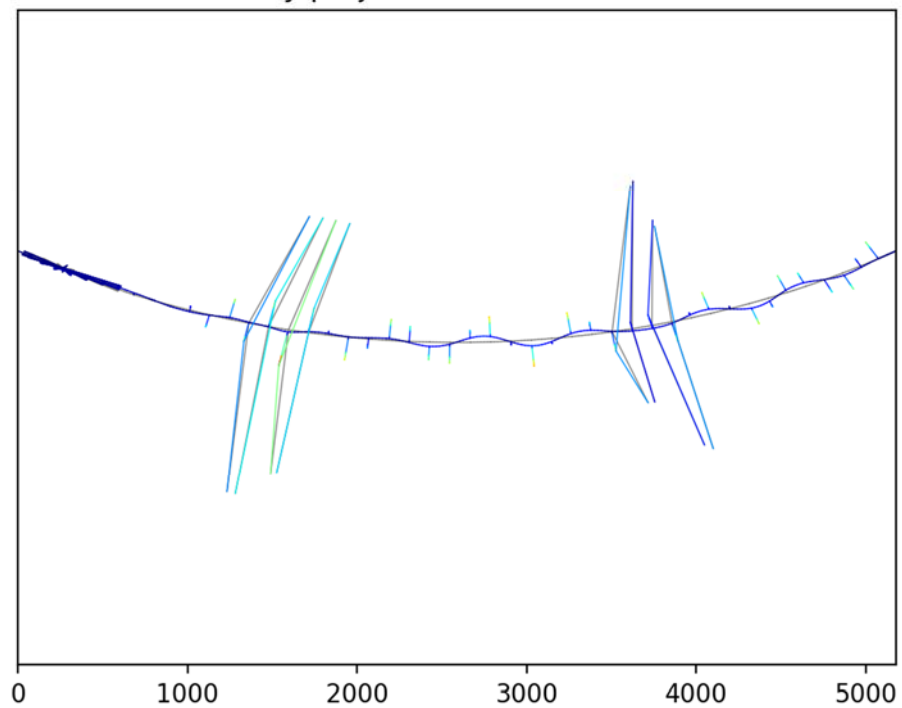
xz projection for mode 80
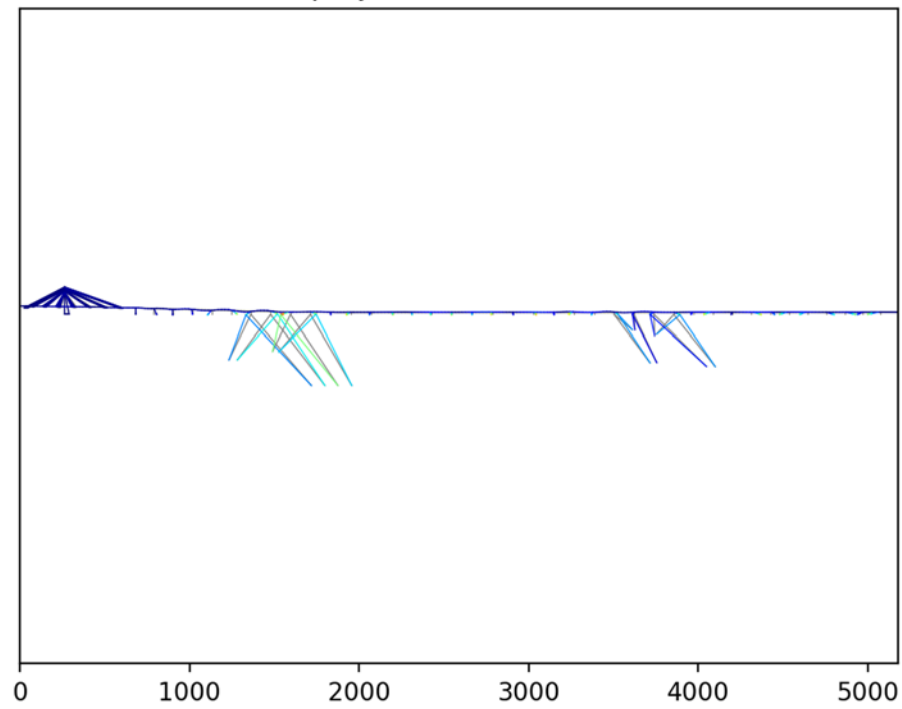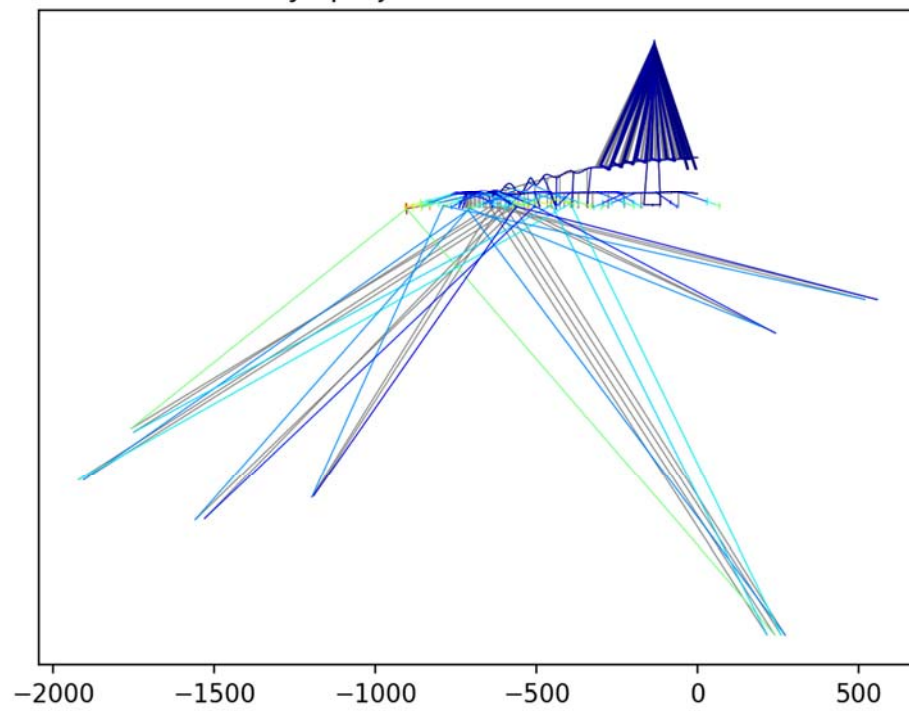

yz projection for mode 80

iso projection for mode 81
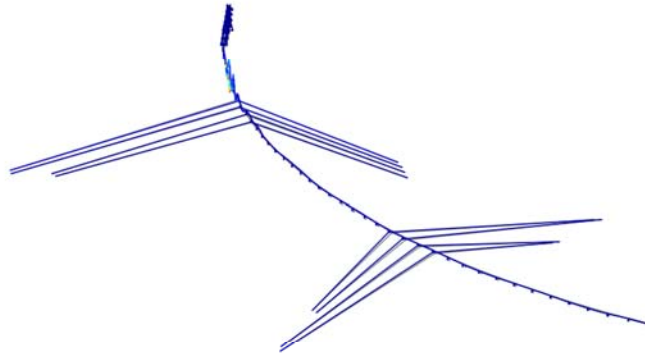

xy projection for mode 81
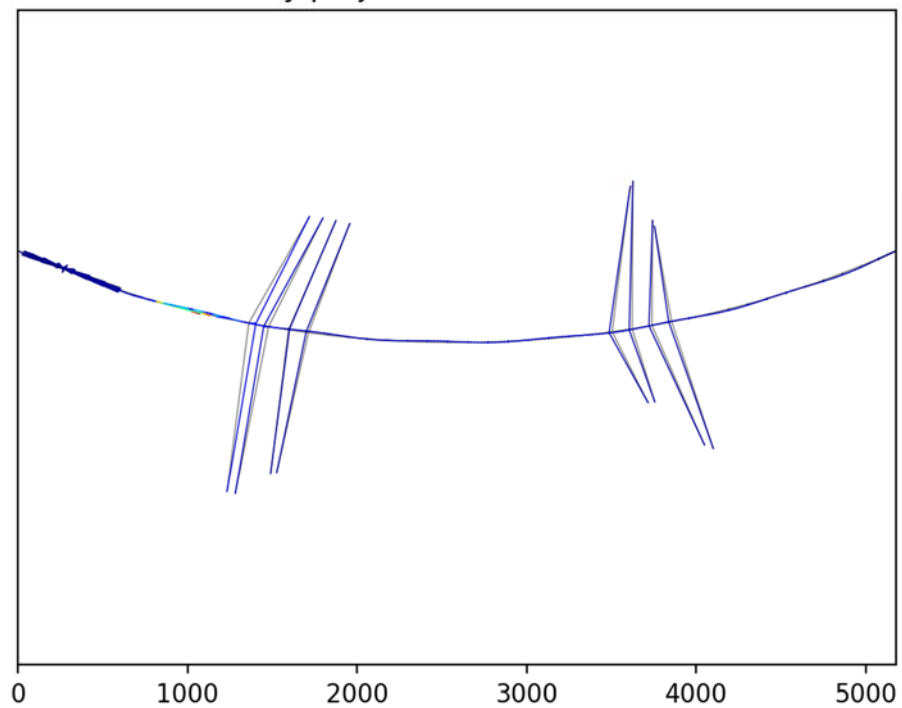
xz projection for mode 81
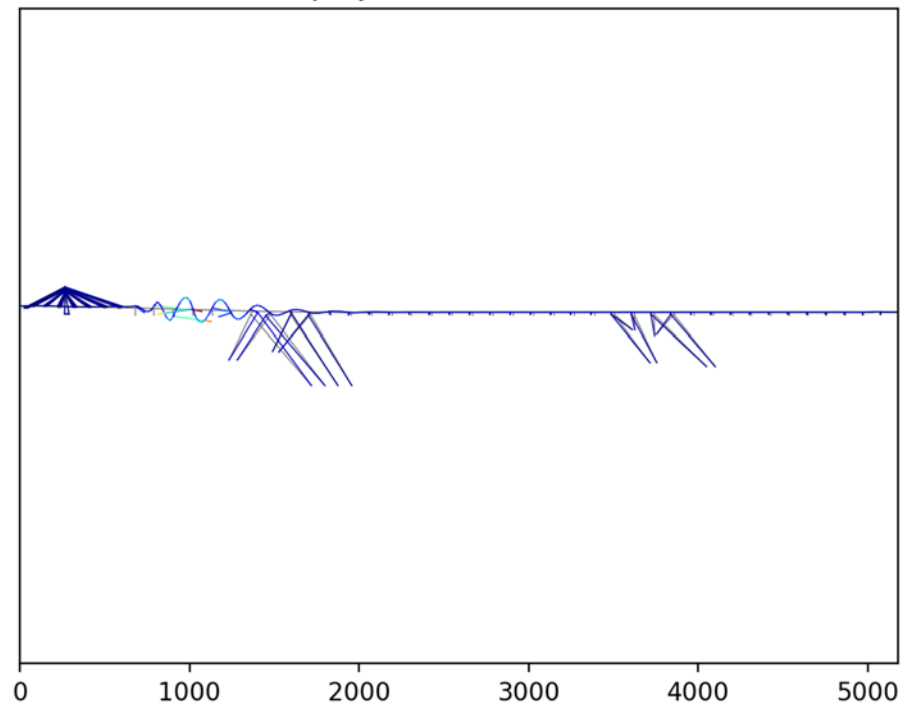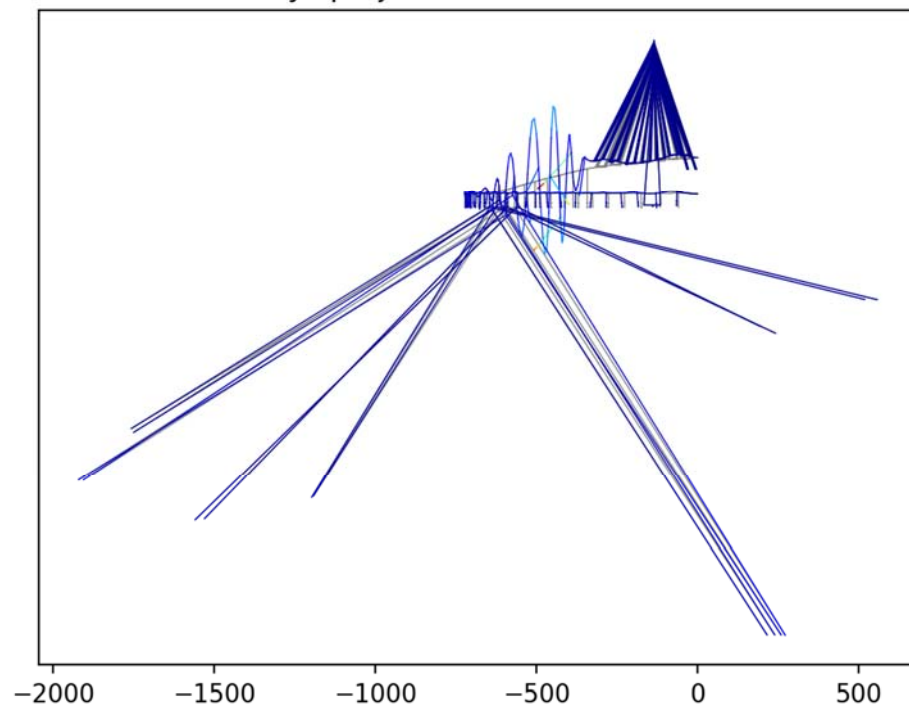

yz projection for mode 81

iso projection for mode 82
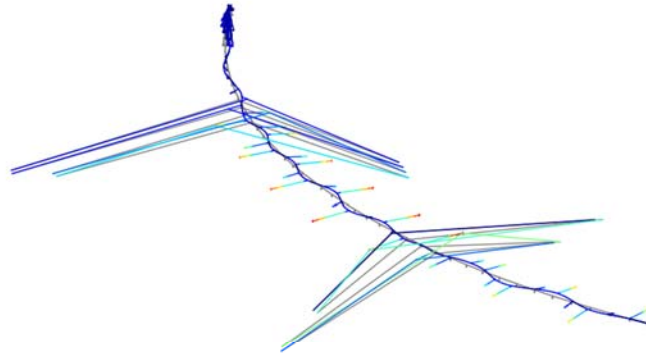

xy projection for mode 82
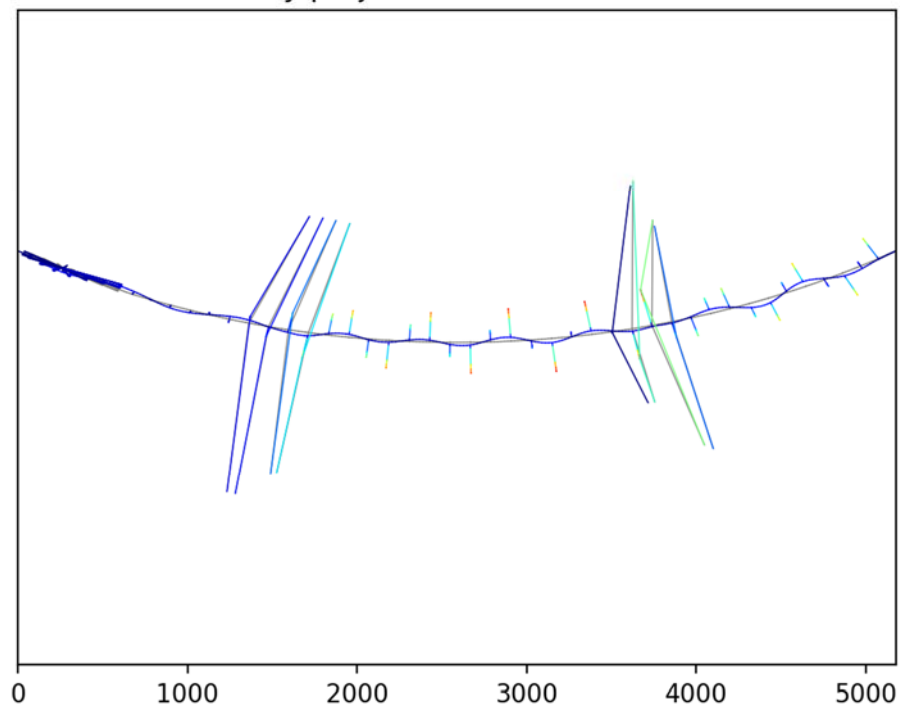
xz projection for mode 82
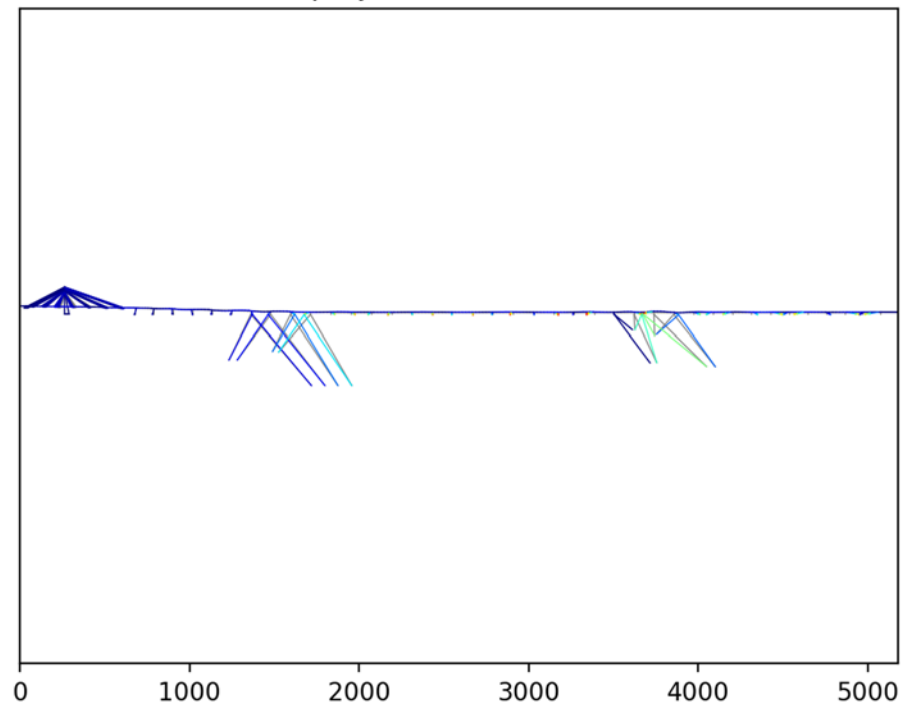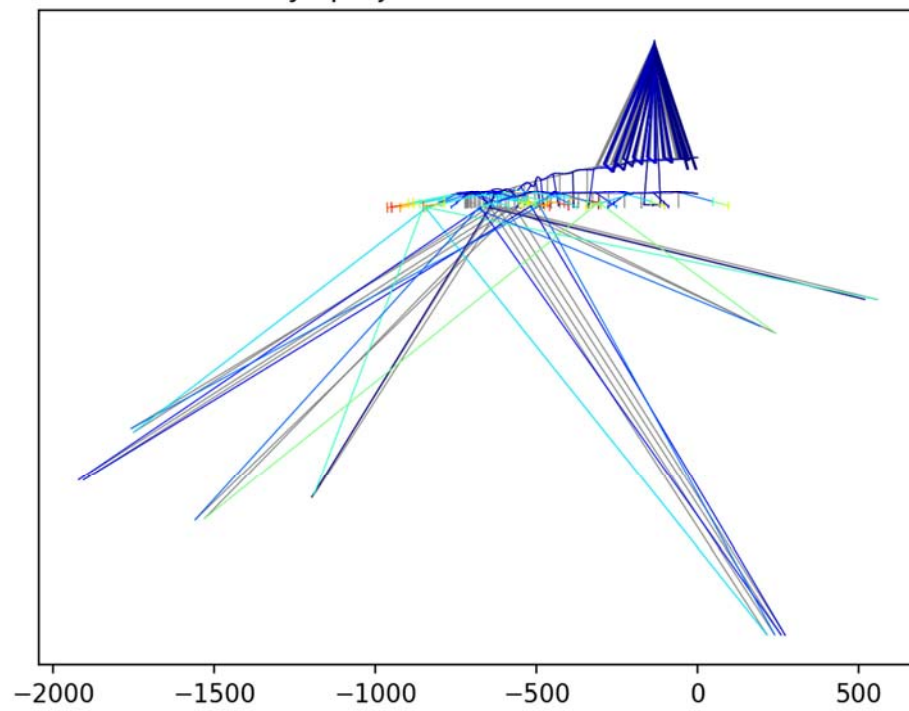

yz projection for mode 82

iso projection for mode 83
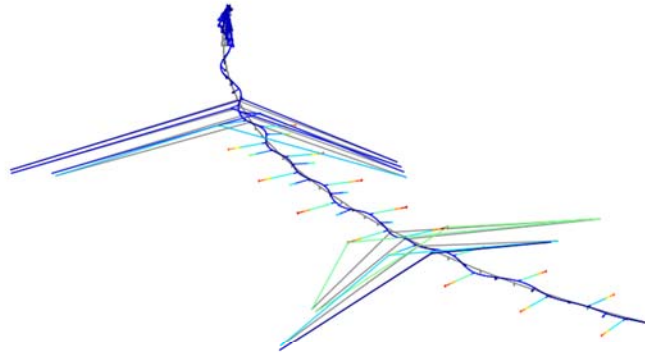

xy projection for mode 83
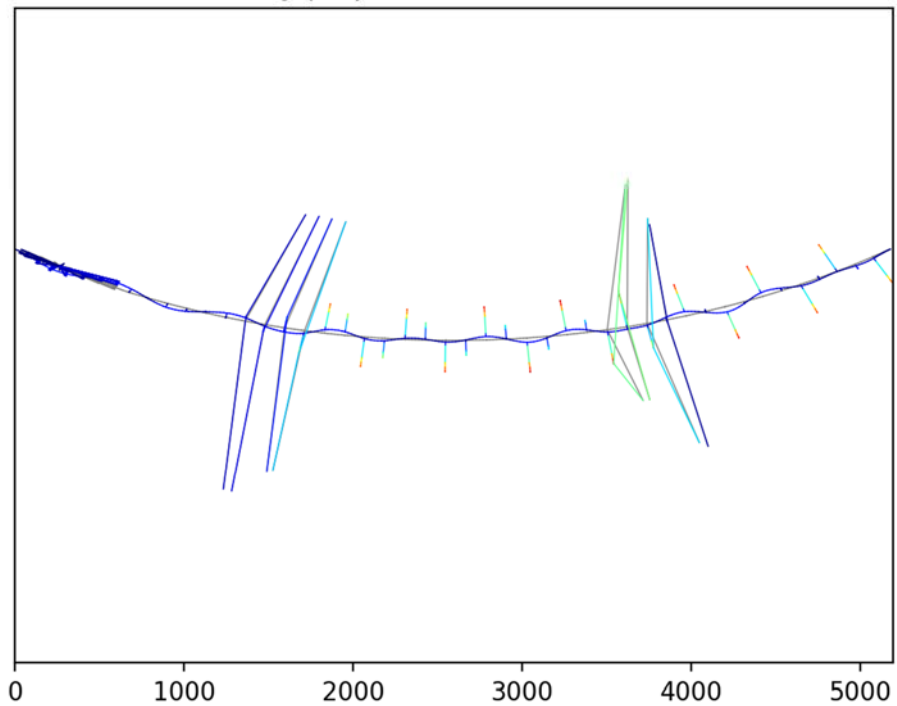
xz projection for mode 83
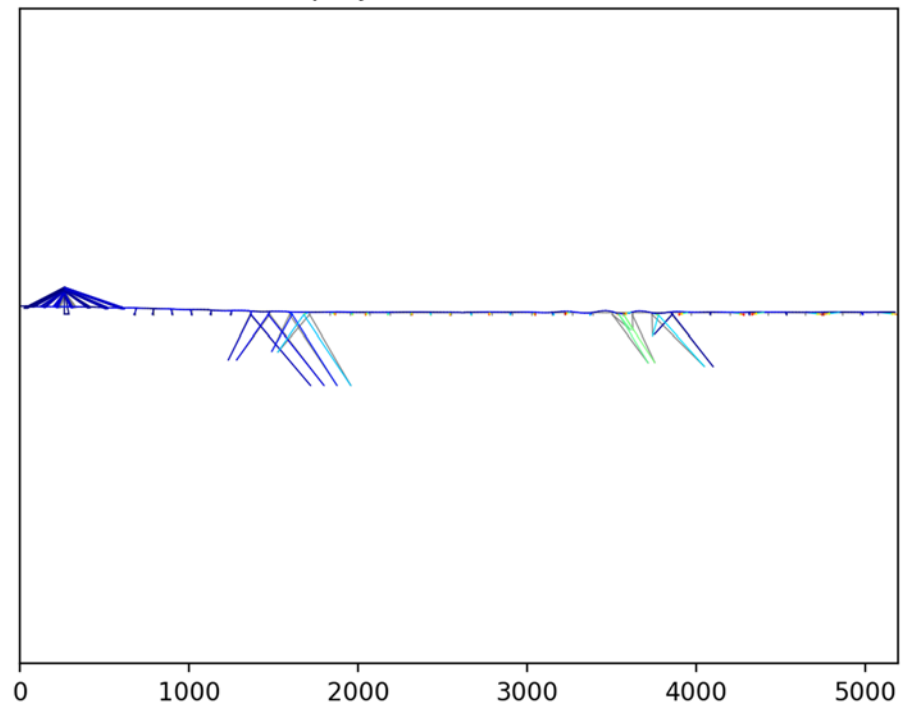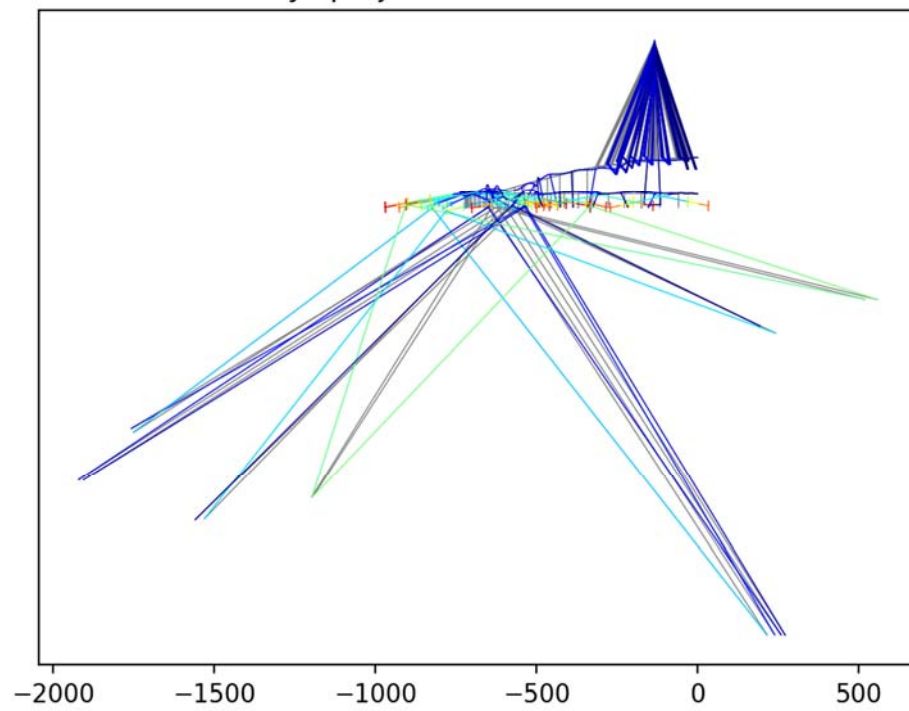

yz projection for mode 83

iso projection for mode 84
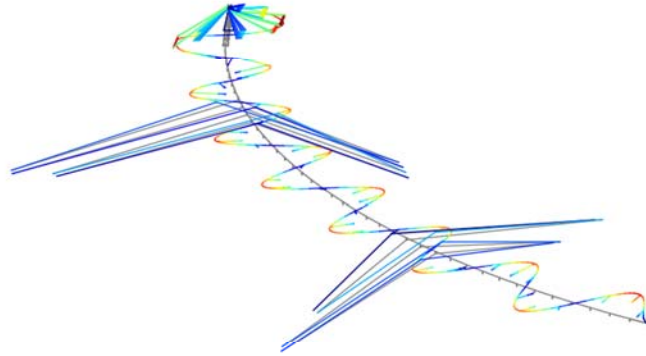

xy projection for mode 84
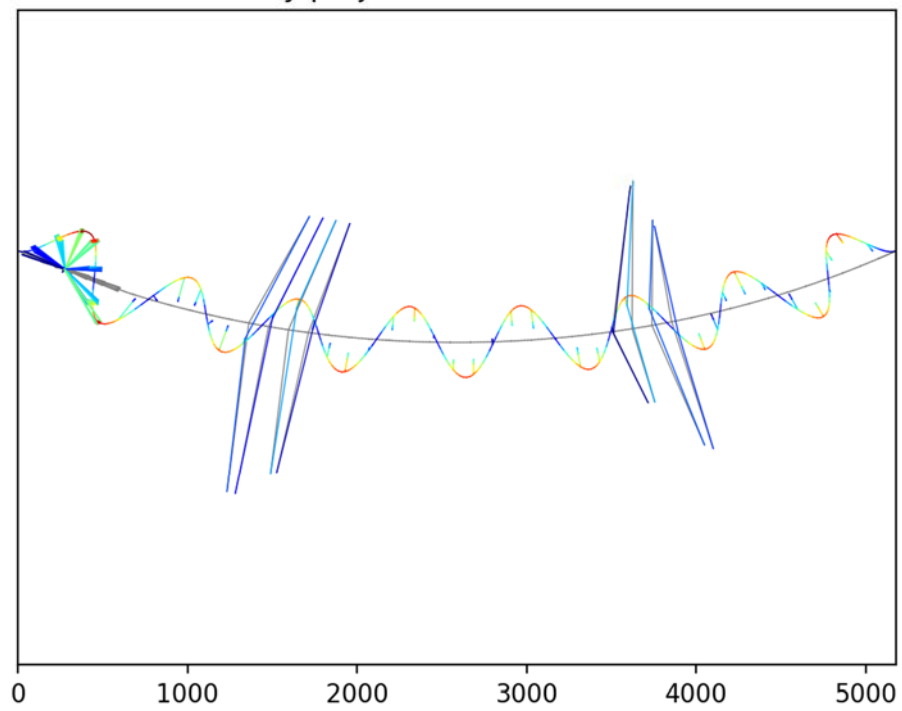
xz projection for mode 84
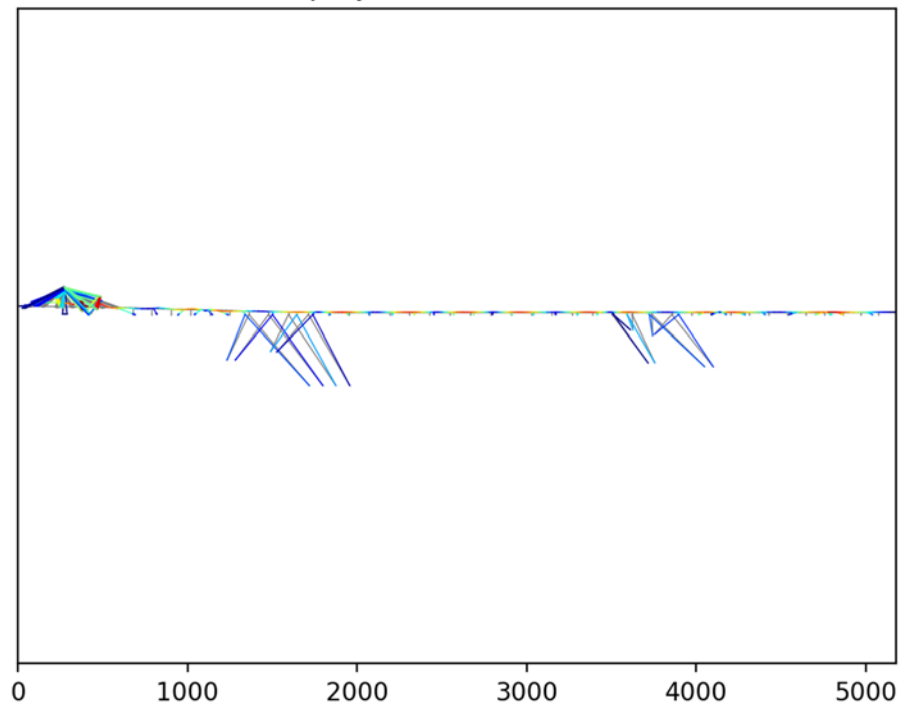

yz projection for mode 84

iso projection for mode 85

xy projection for mode 85

xz projection for mode 85

yz projection for mode 85

iso projection for mode 86

xy projection for mode 86
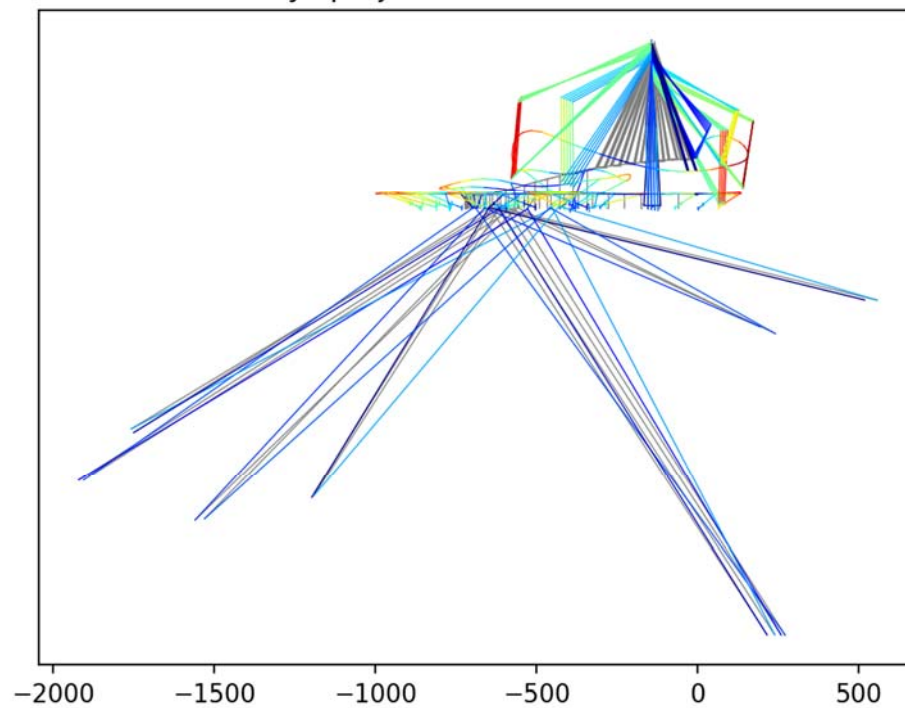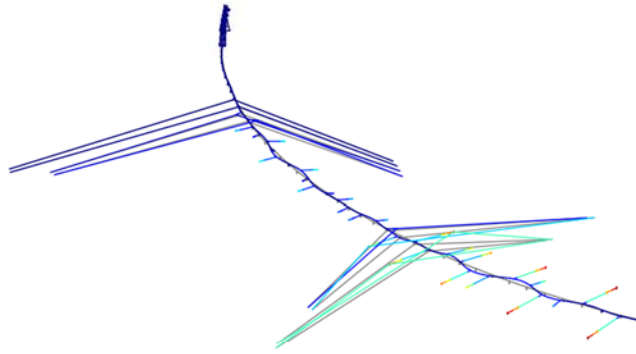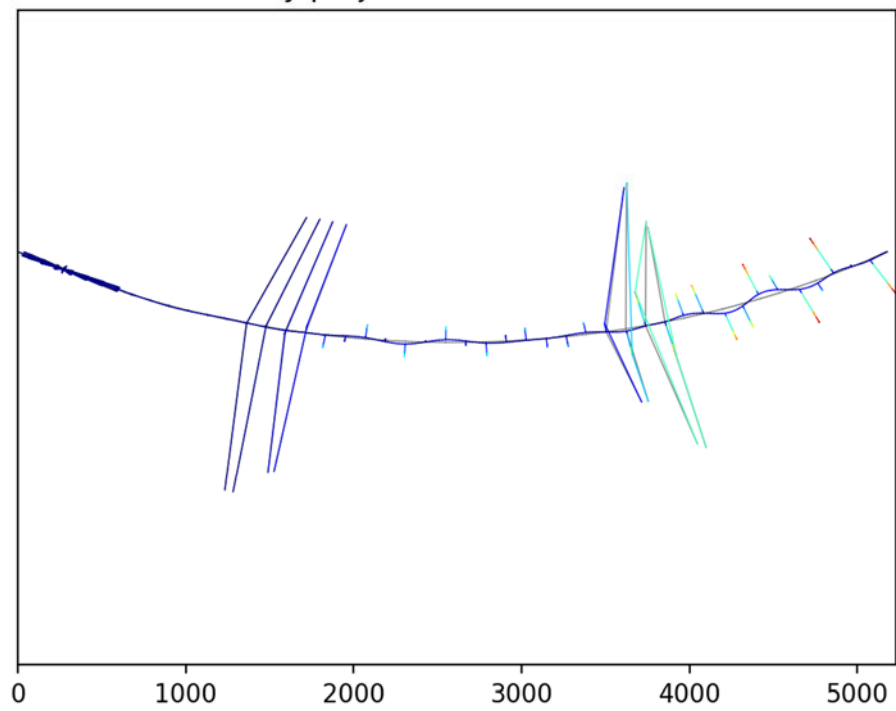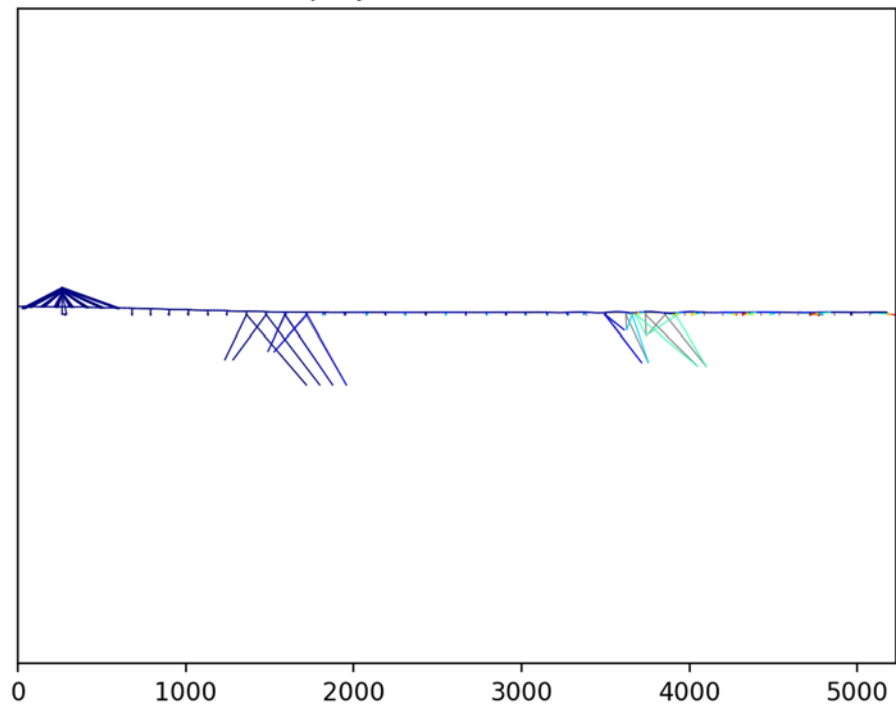
xz projection for mode 86

yz projection for mode 86

iso projection for mode 87

xy projection for mode 87
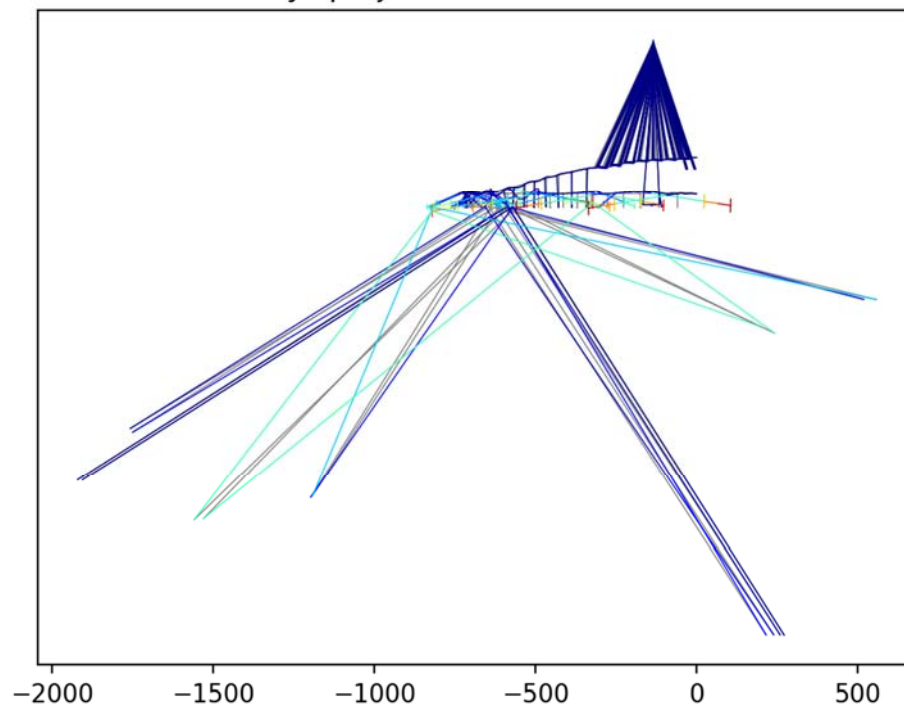
xz projection for mode 87

yz projection for mode 87

iso projection for mode 88
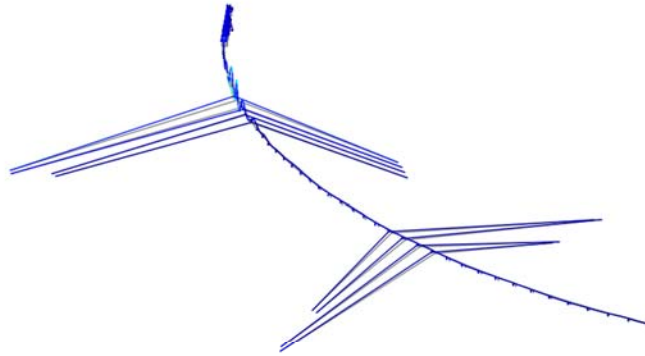

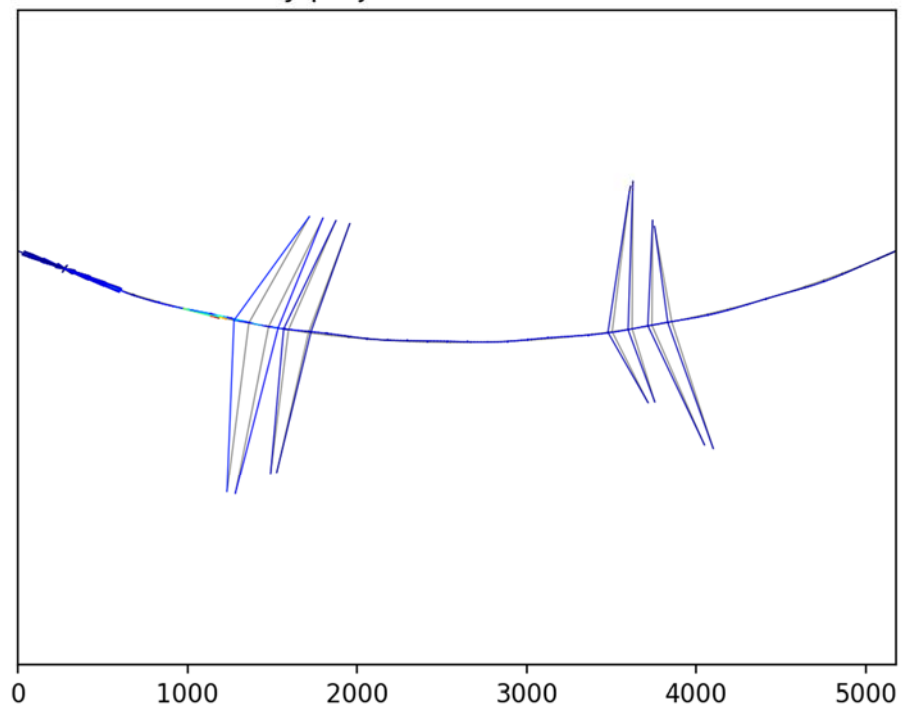xy projection for mode 88

xz projection for mode 88
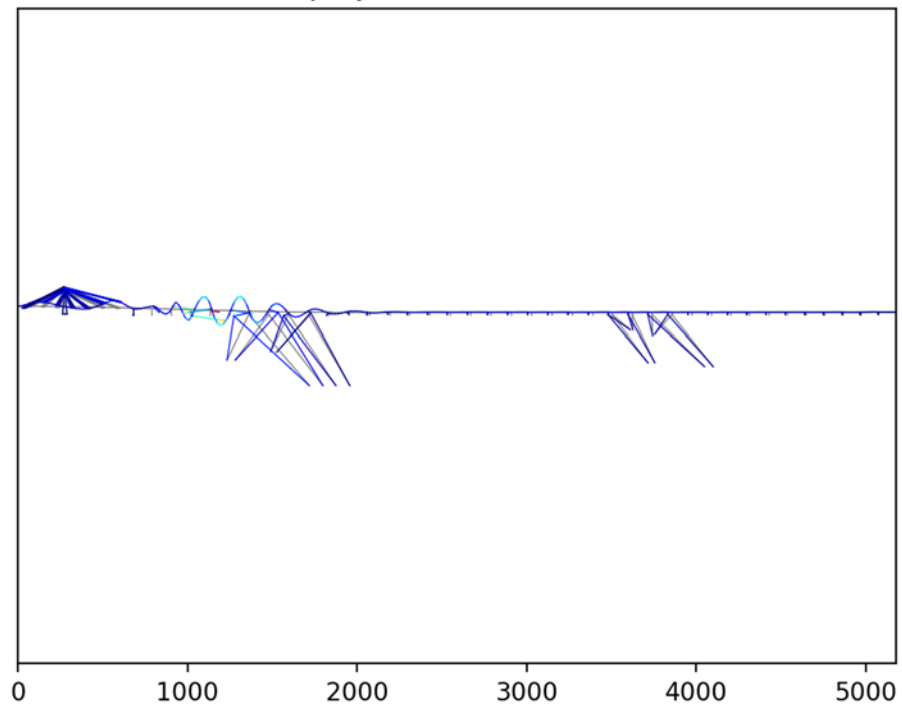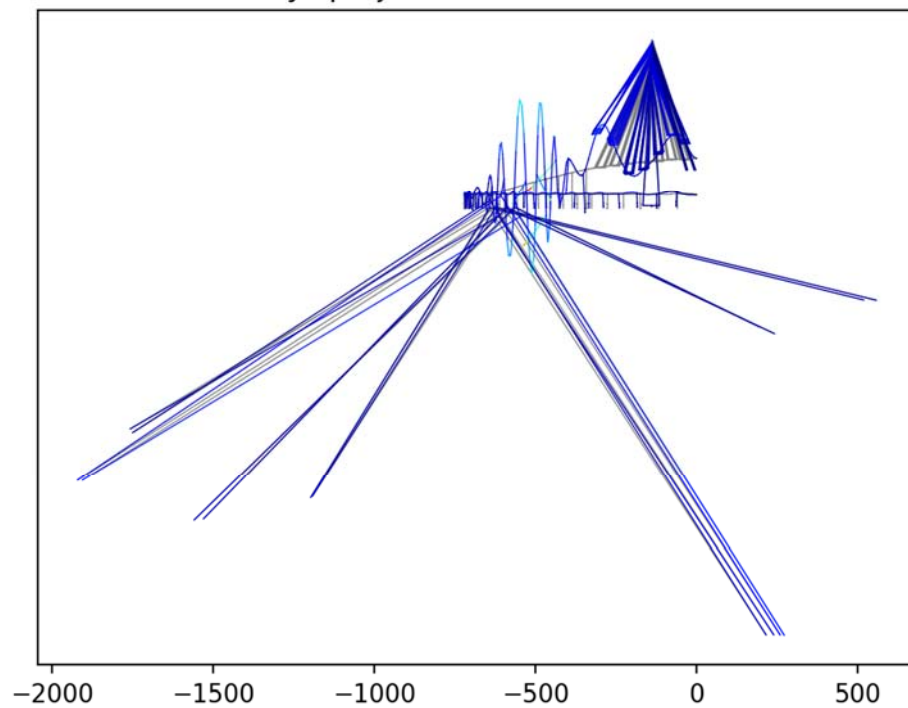

yz projection for mode 88

iso projection for mode 89
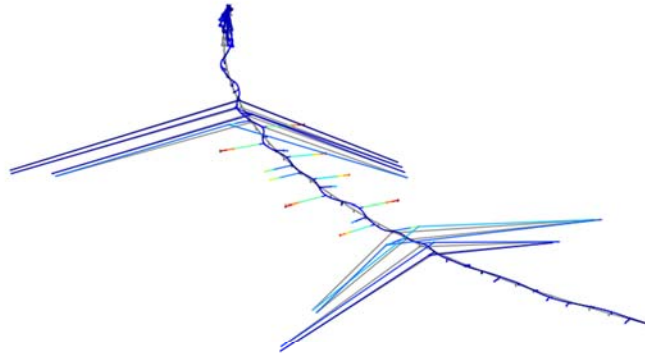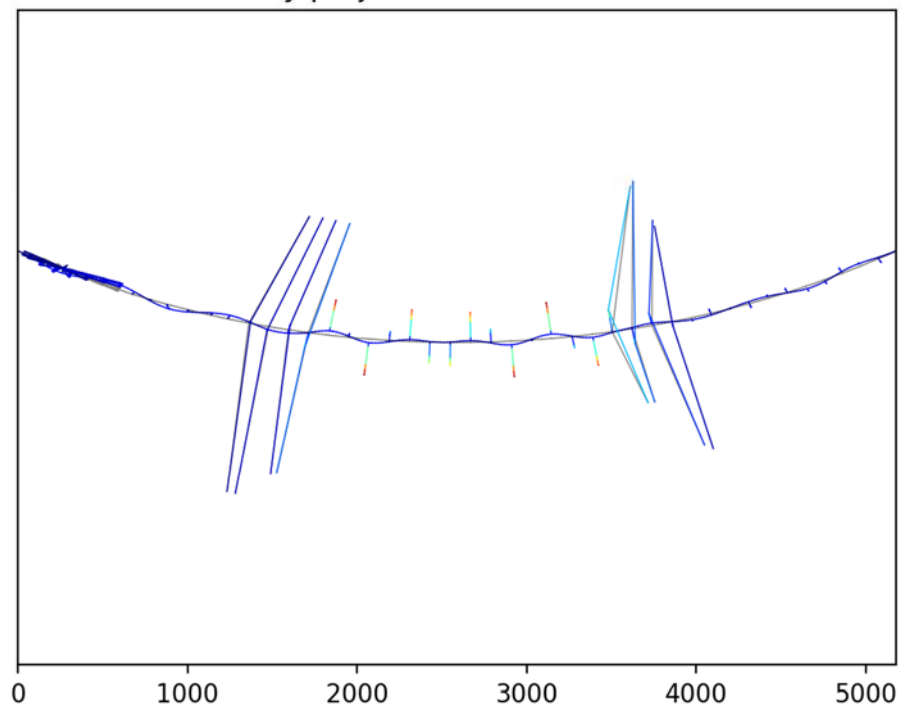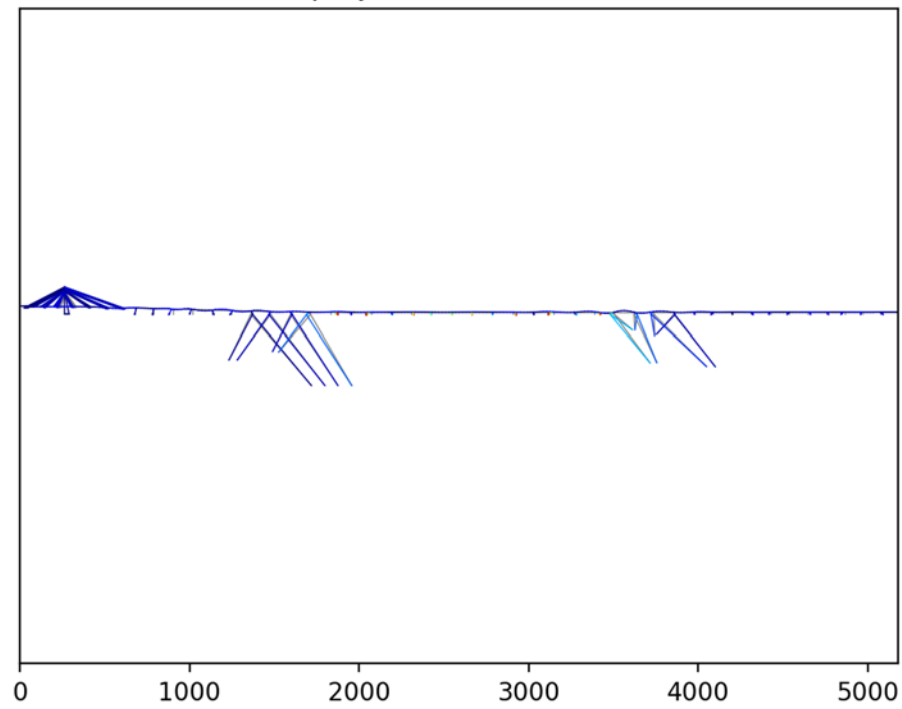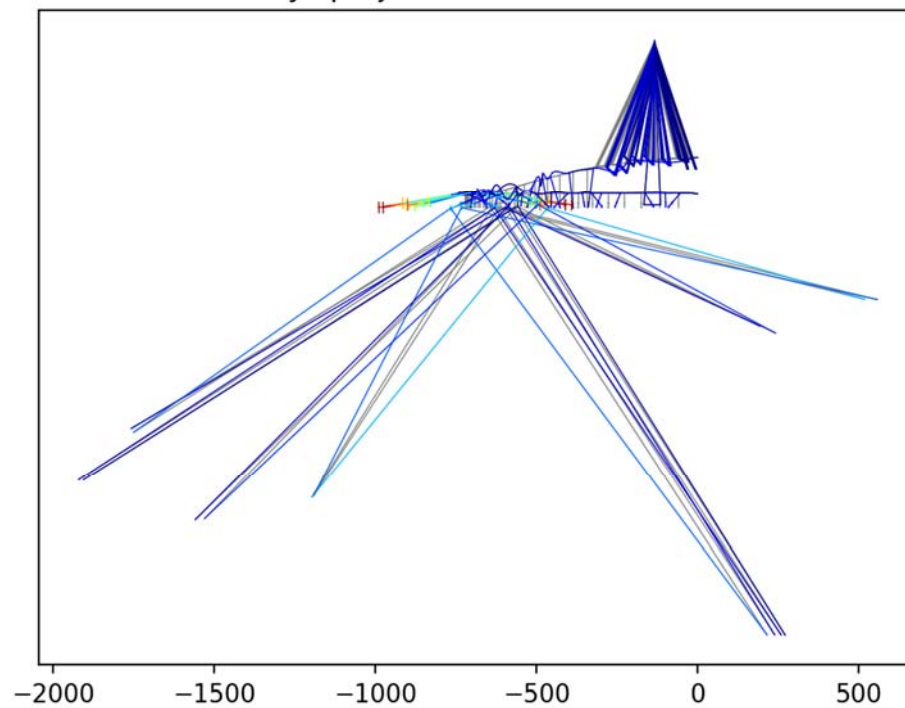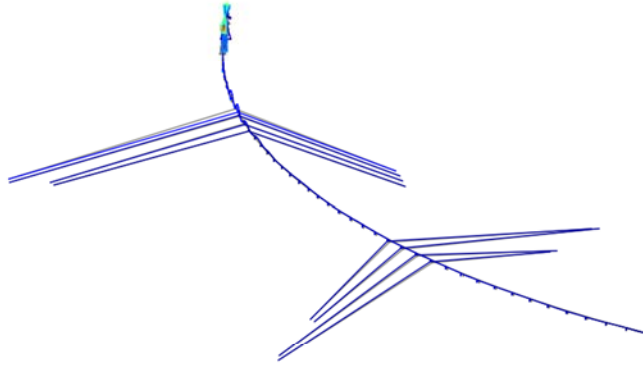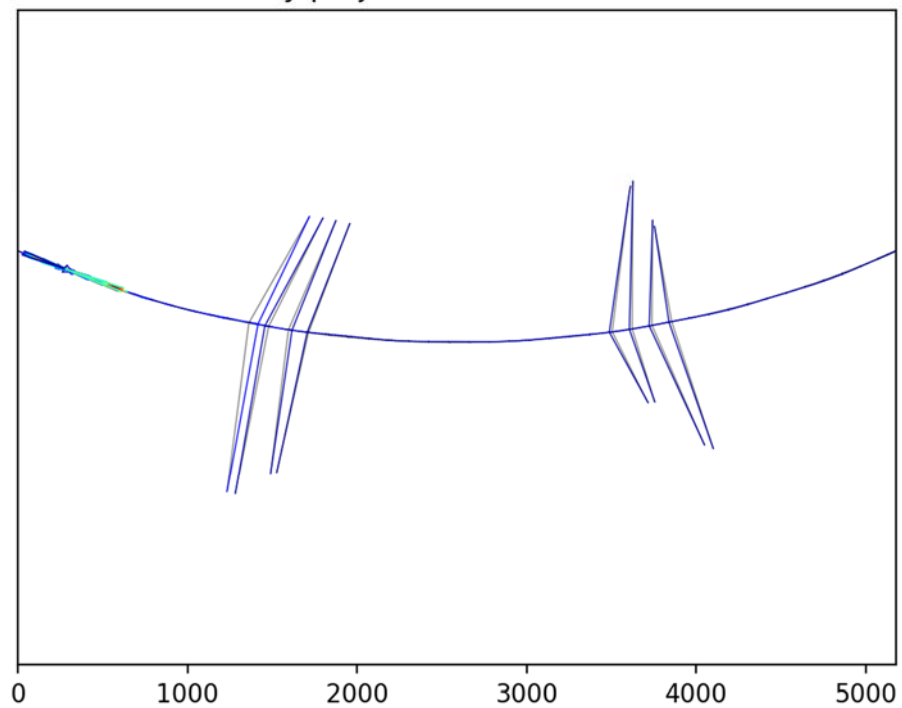

xy projection for mode 89

xz projection for mode 89

yz projection for mode 89

iso projection for mode 90

xy projection for mode 90

xz projection for mode 90
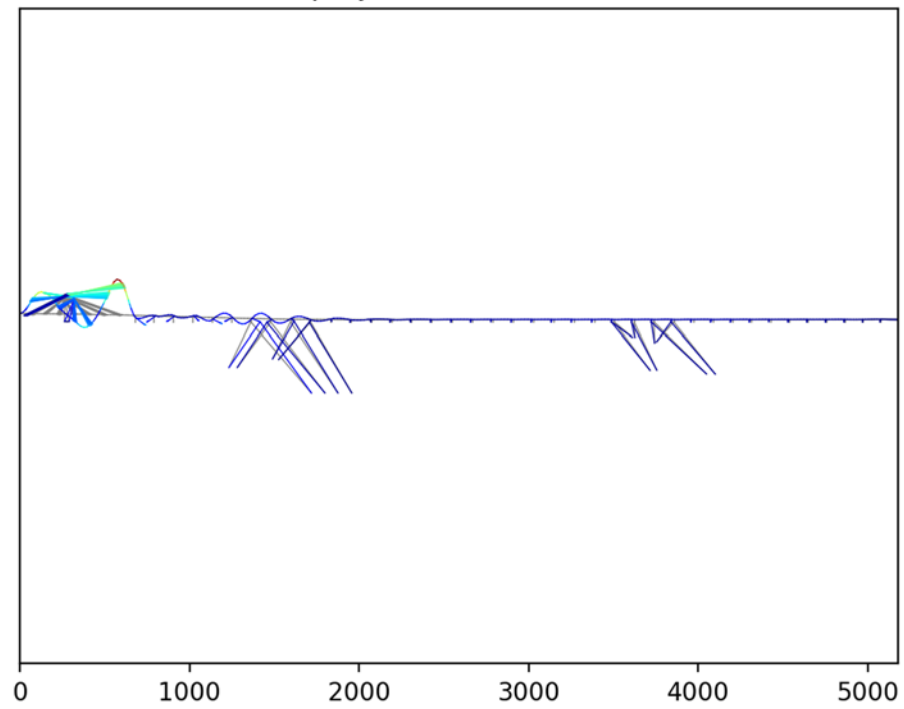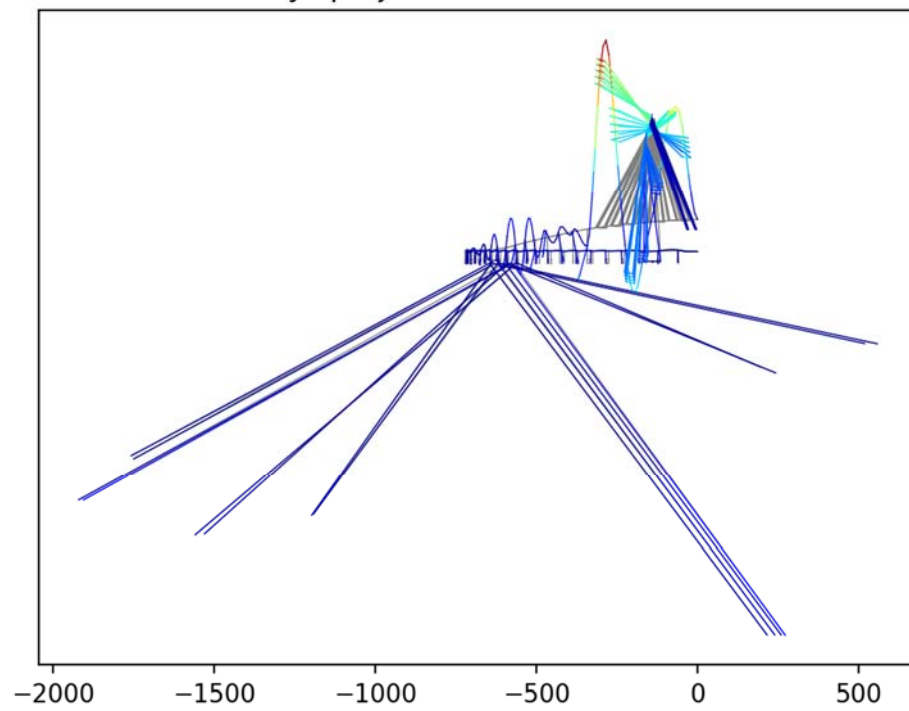

yz projection for mode 90

iso projection for mode 91
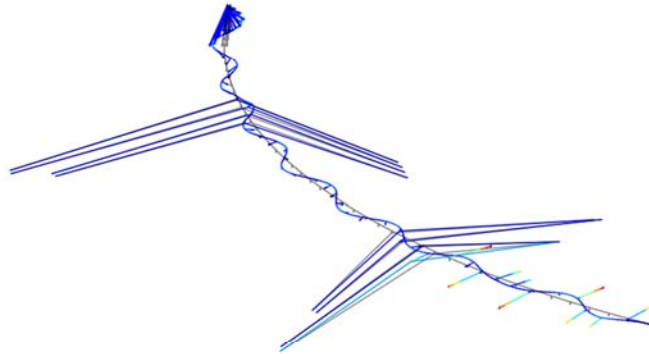

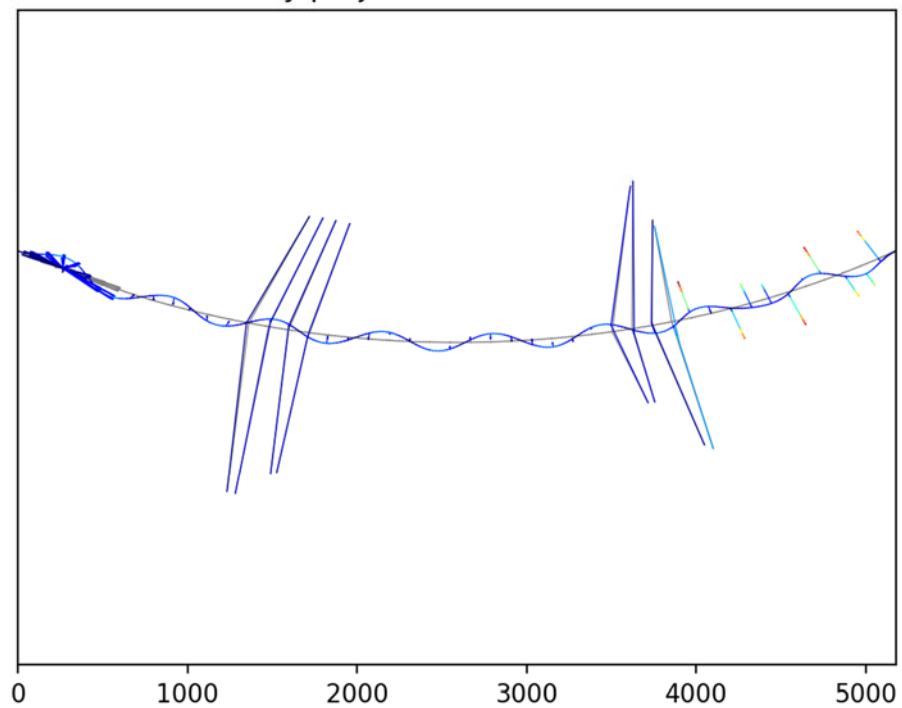xy projection for mode 91

xz projection for mode 91
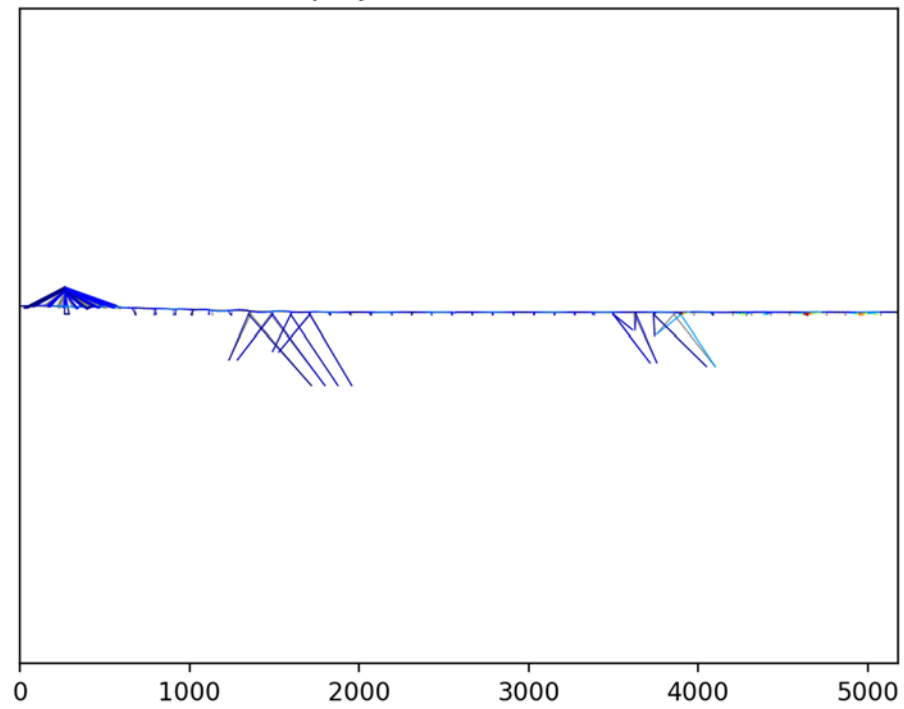

yz projection for mode 91

iso projection for mode 92

xy projection for mode 92

xz projection for mode 92

yz projection for mode 92

iso projection for mode 93

xy projection for mode 93
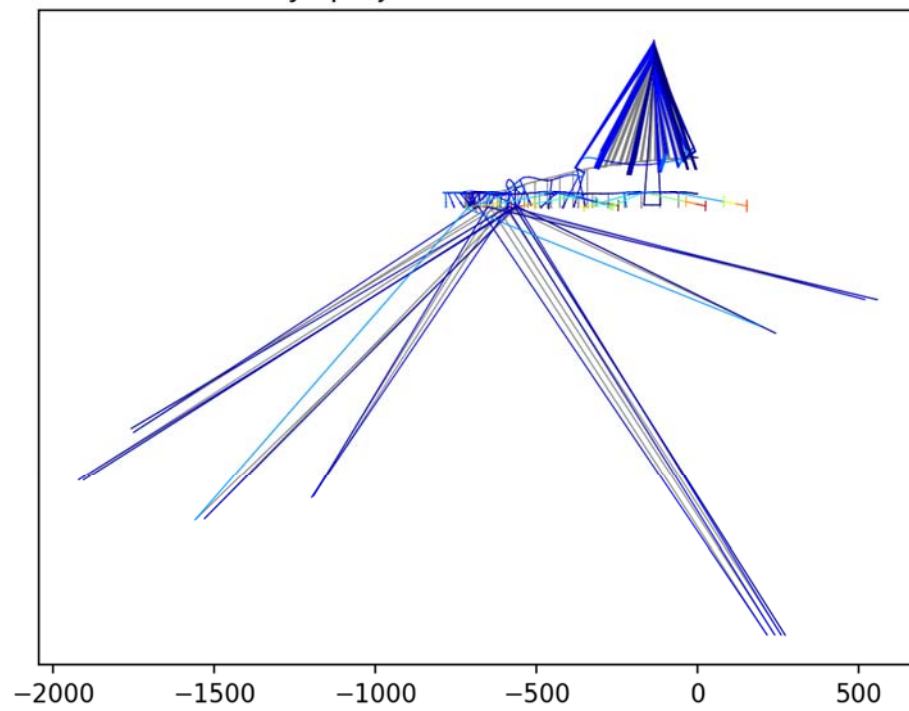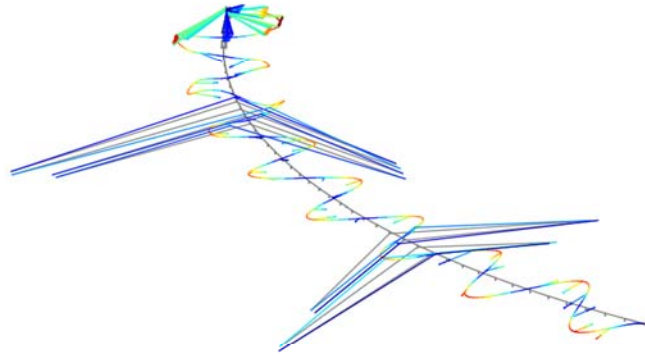
xz projection for mode 93

yz projection for mode 93

iso projection for mode 94

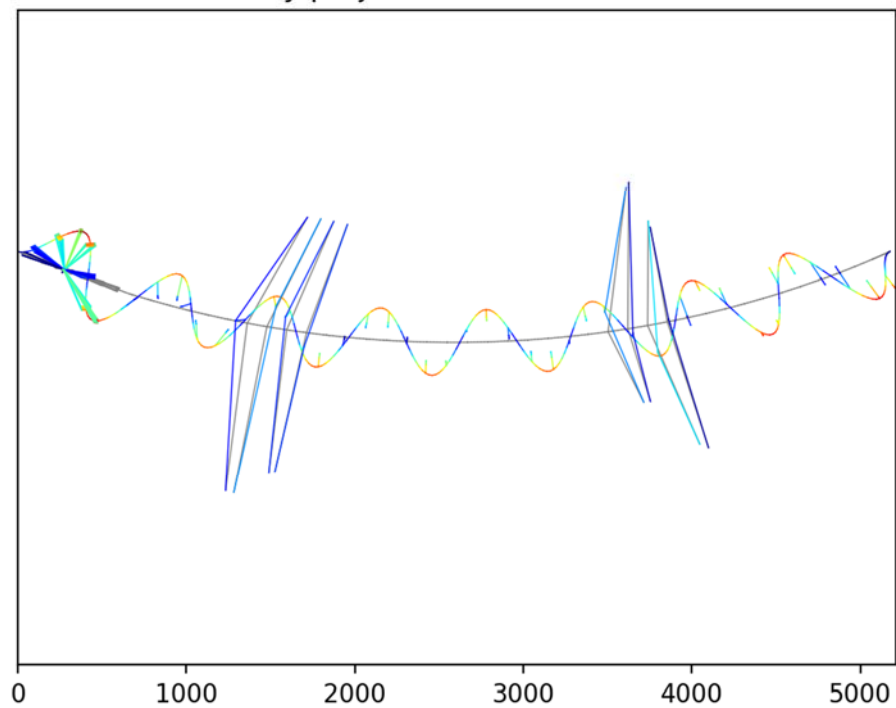xy projection for mode 94

xz projection for mode 94
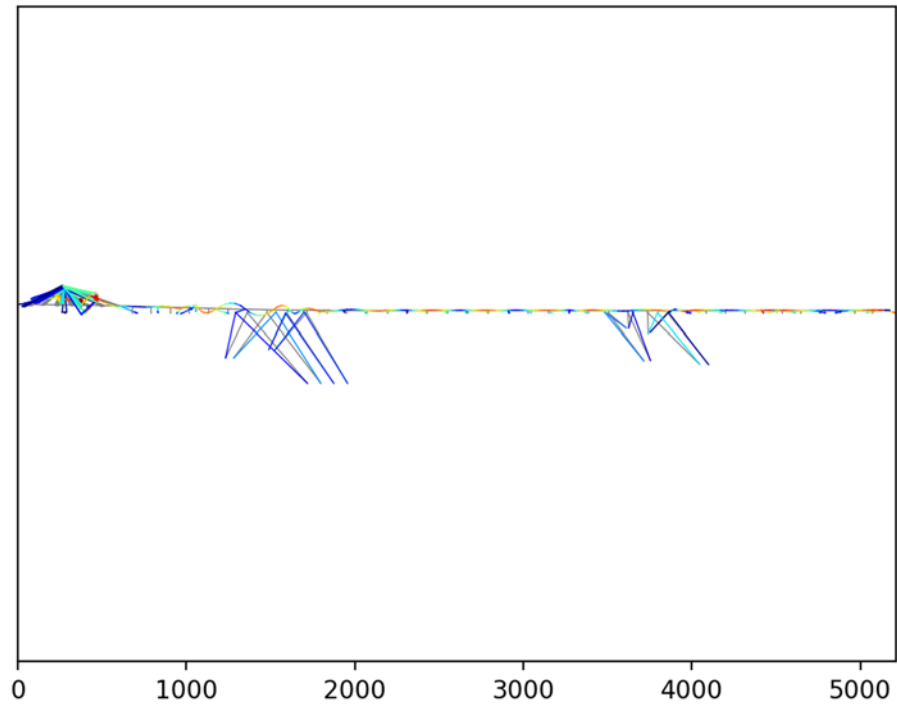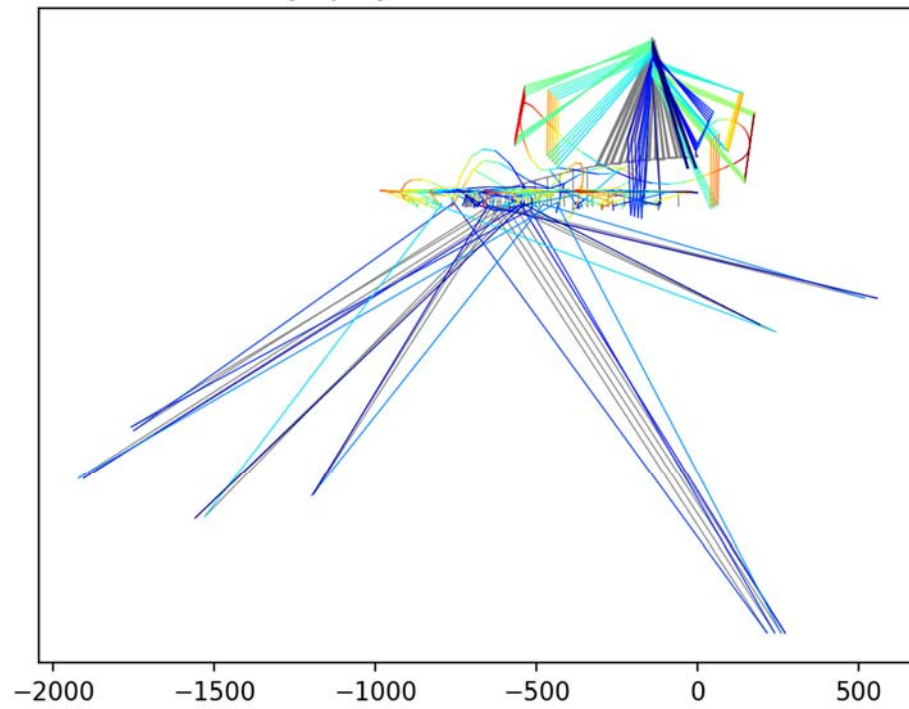

yz projection for mode 94

iso projection for mode 95
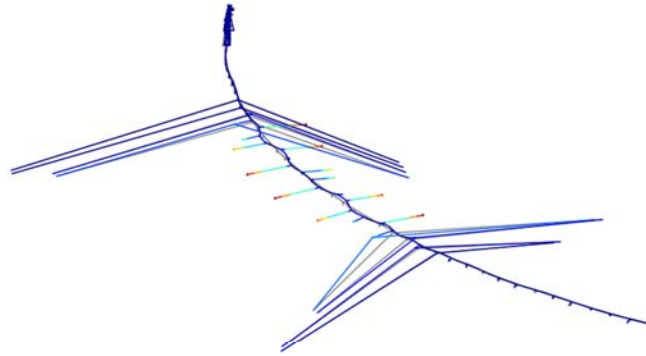

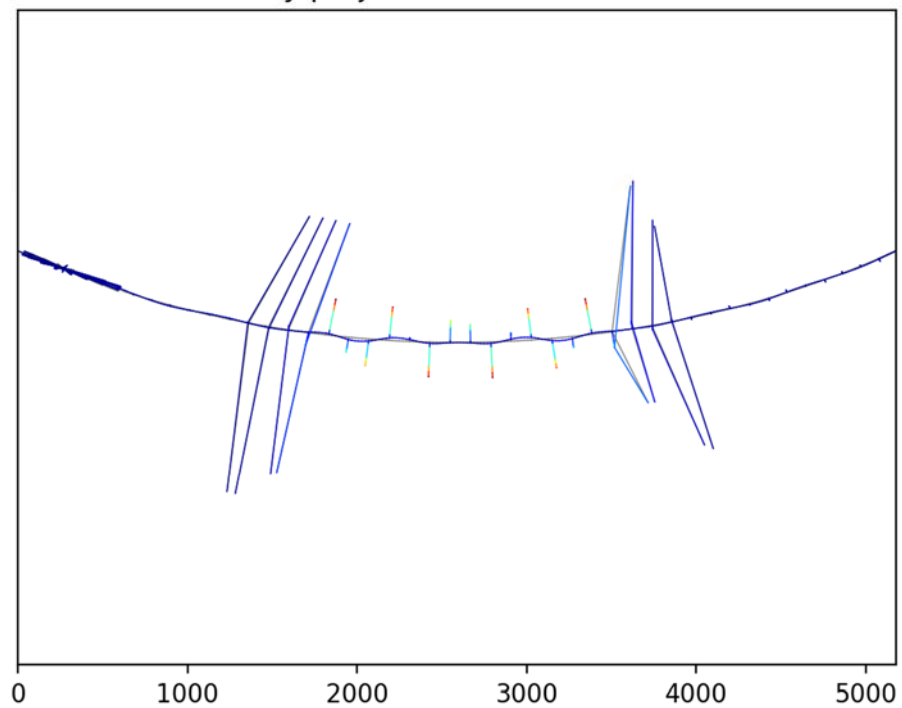xy projection for mode 95

xz projection for mode 95
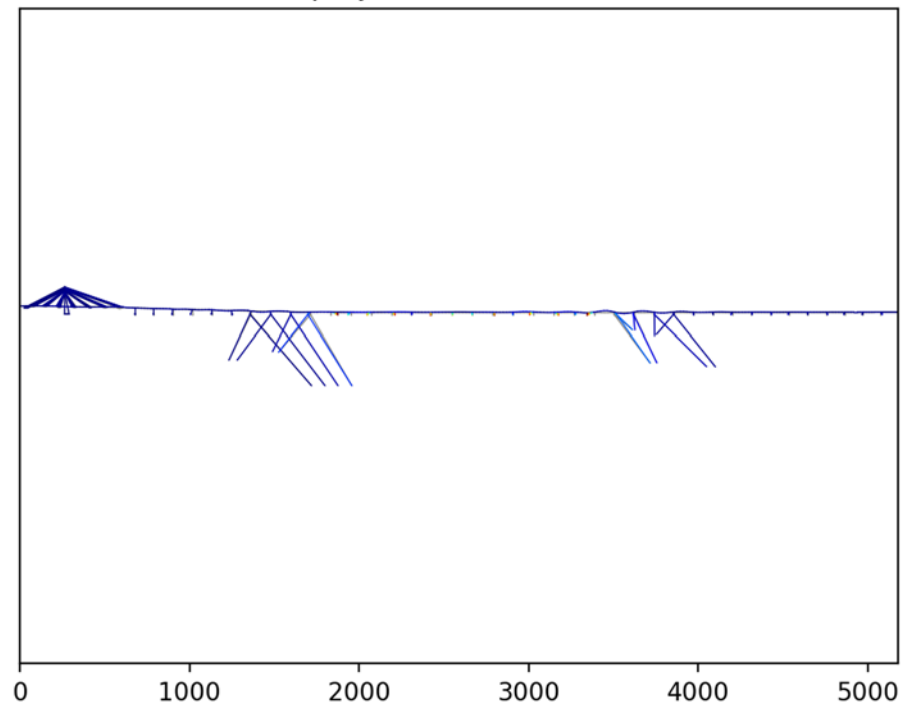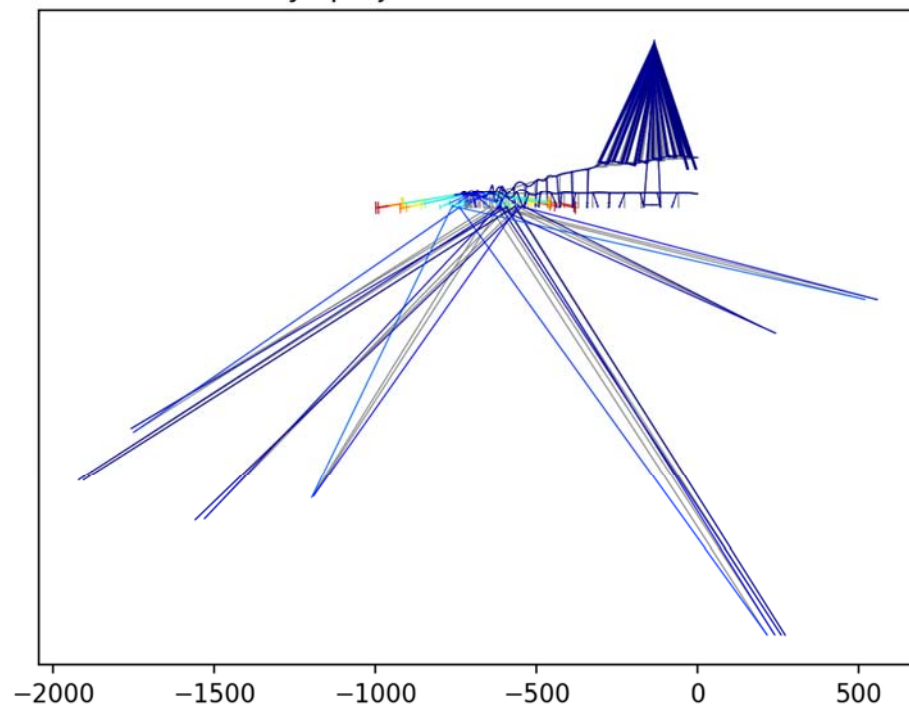

yz projection for mode 95

iso projection for mode 96
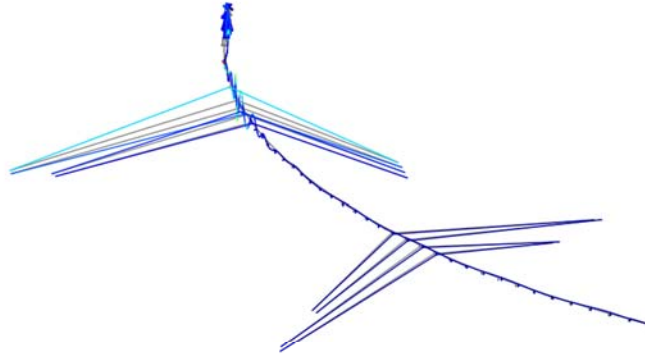

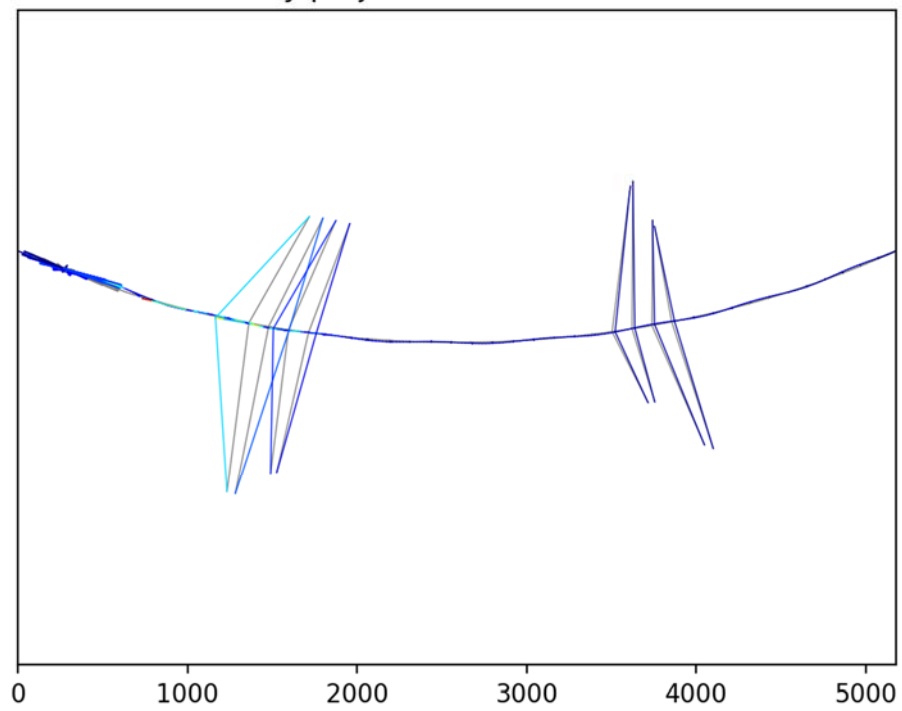xy projection for mode 96

xz projection for mode 96

yz projection for mode 96

iso projection for mode 97

xy projection for mode 97

xz projection for mode 97
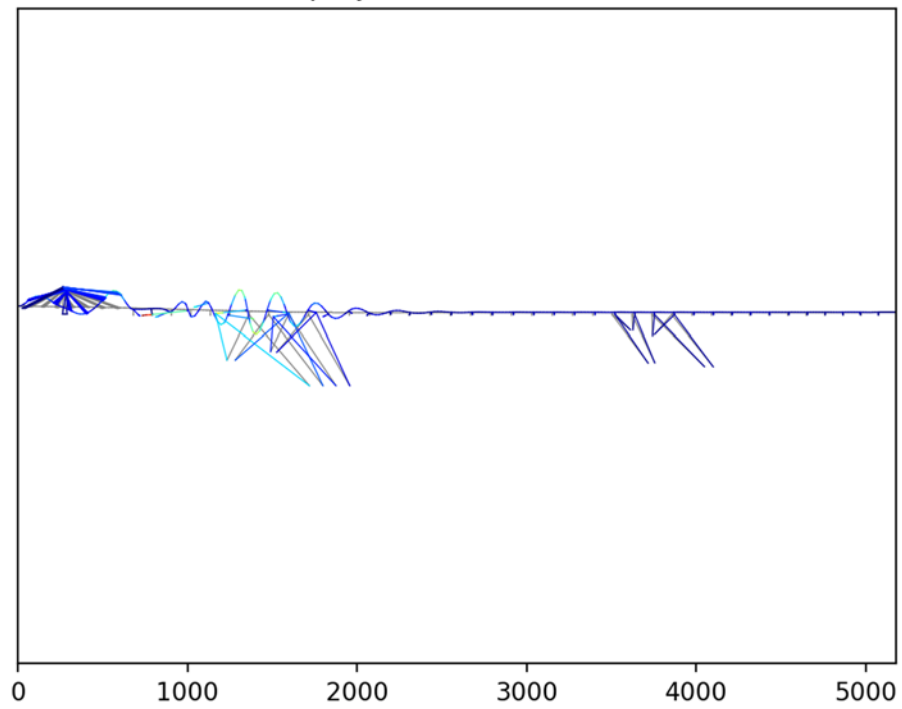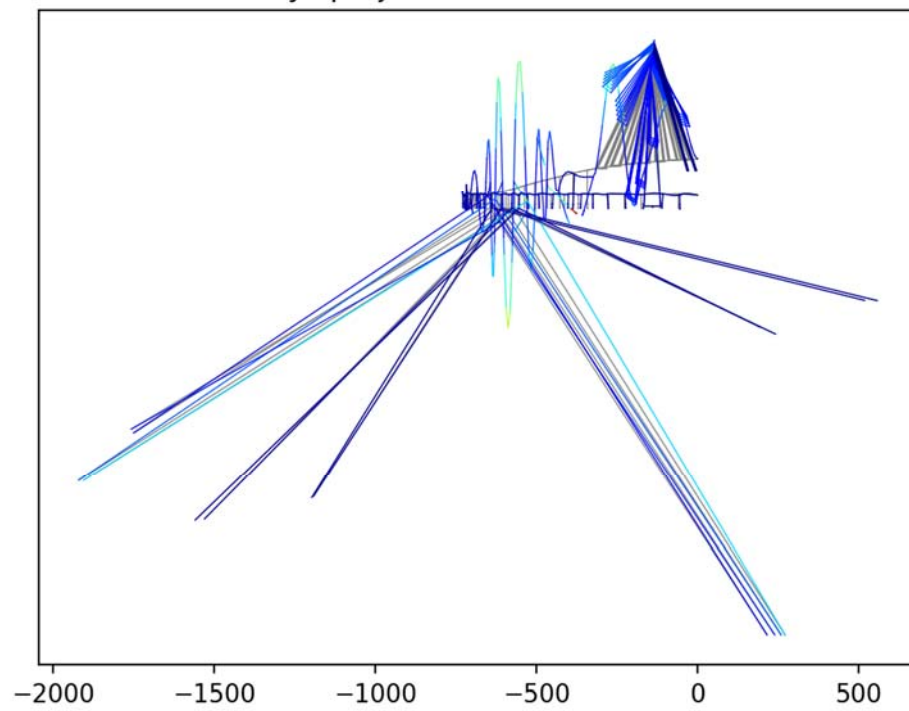

yz projection for mode 97

iso projection for mode 98
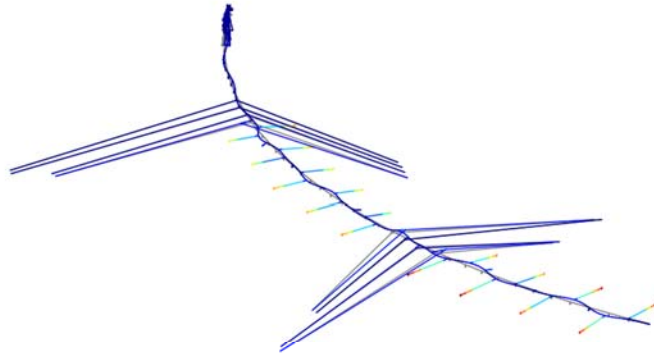

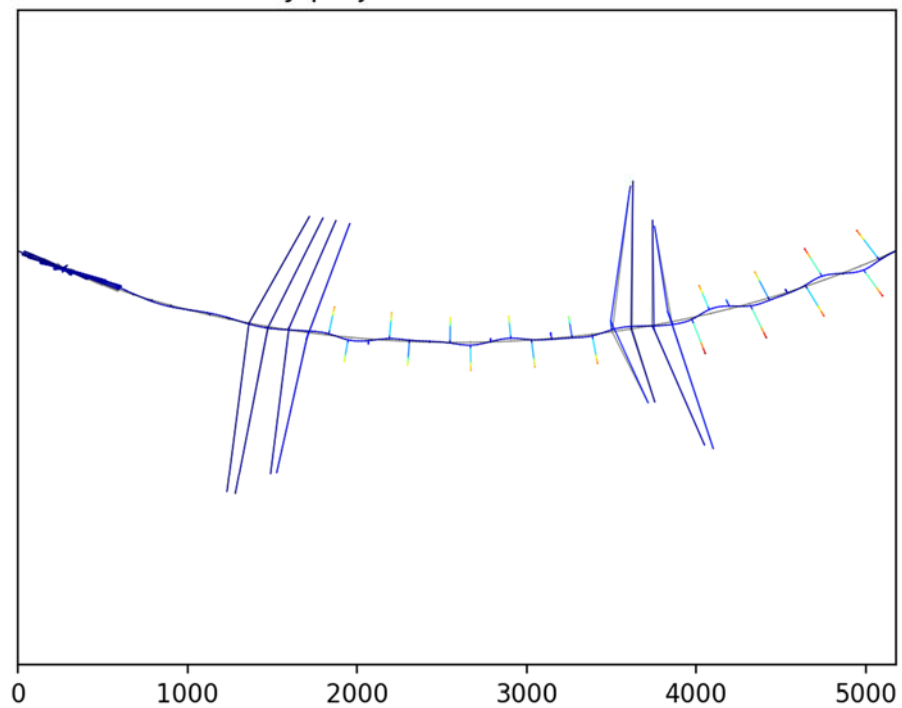xy projection for mode 98

xz projection for mode 98
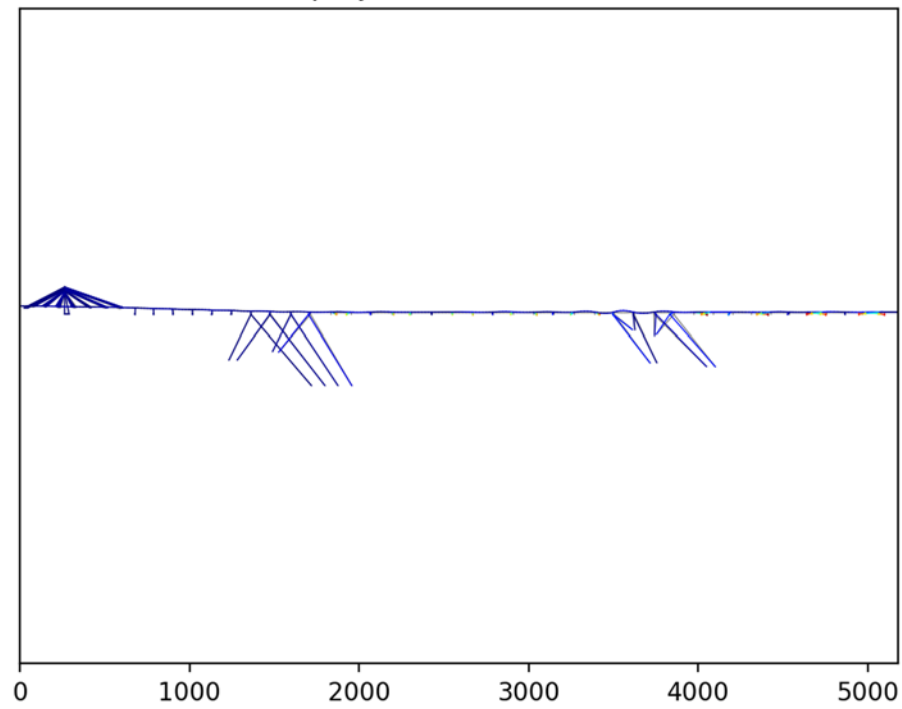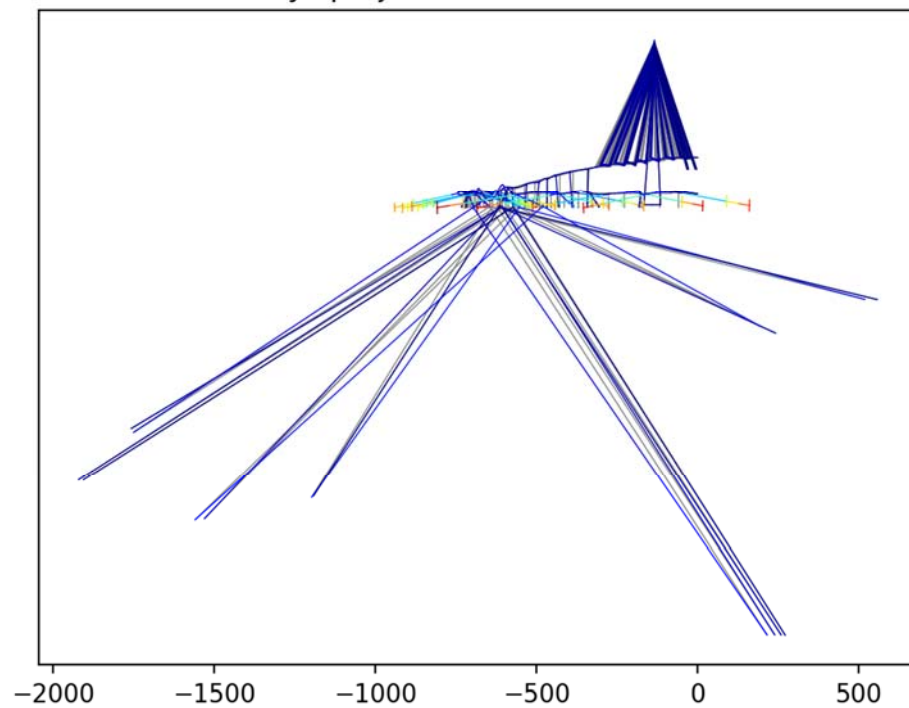

yz projection for mode 98

iso projection for mode 99
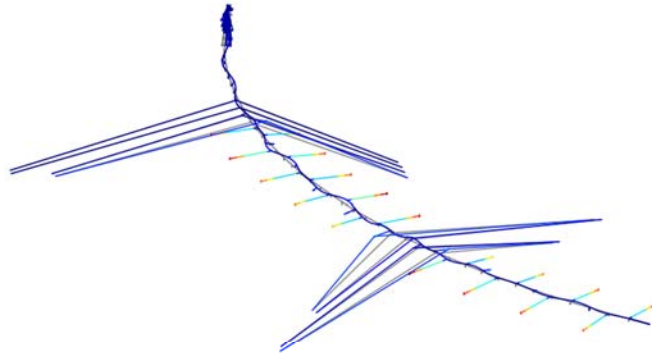

xy projection for mode 99
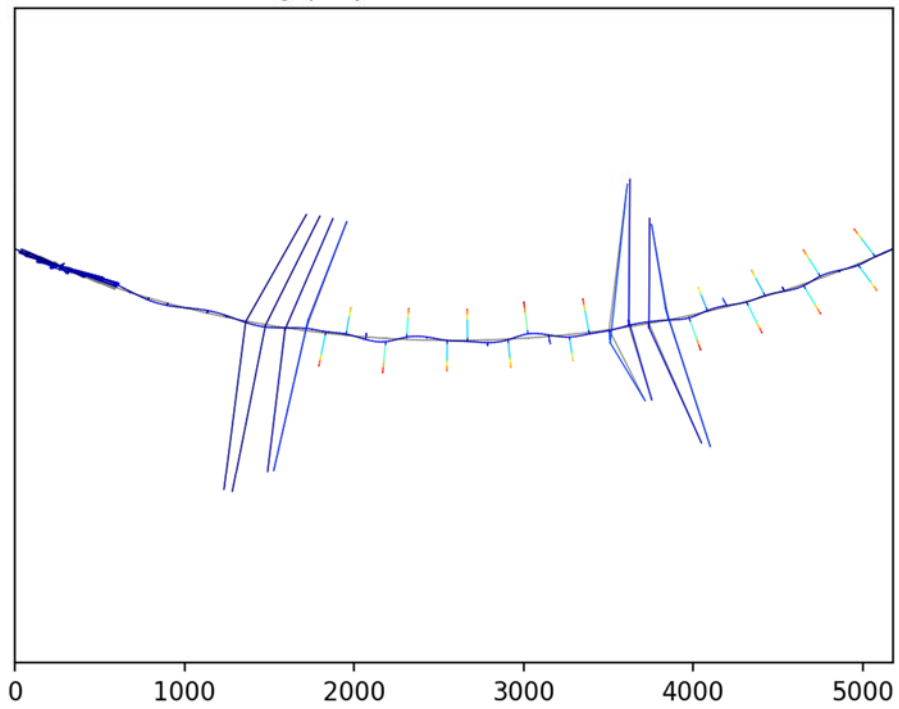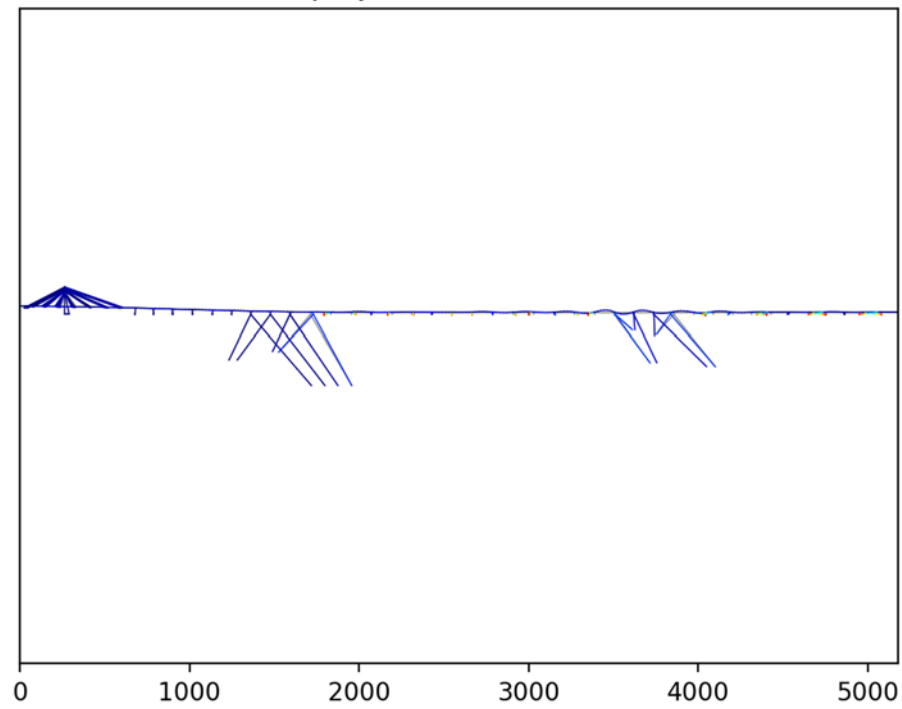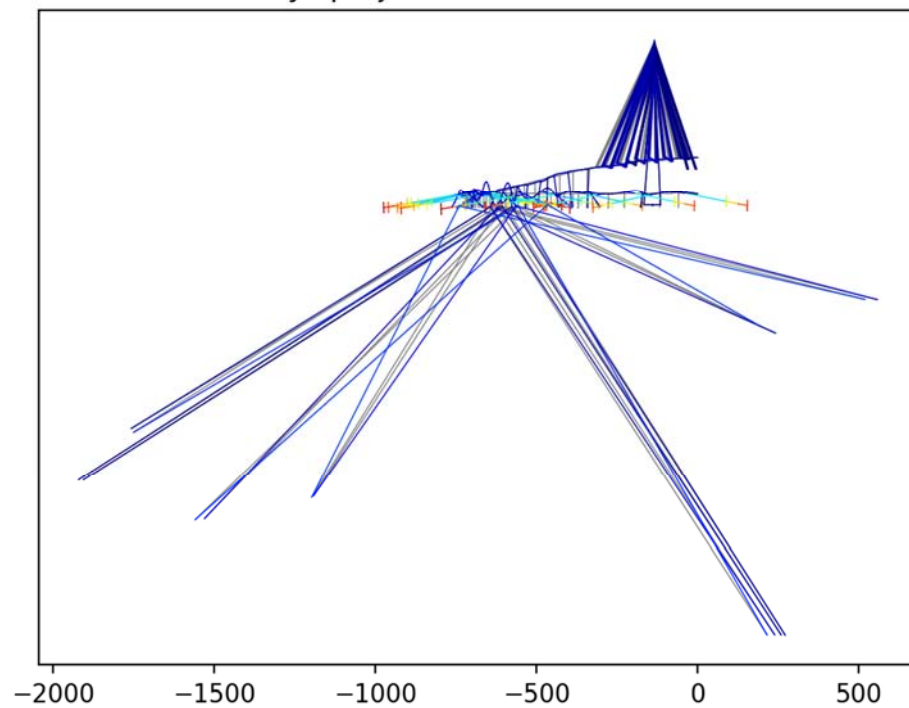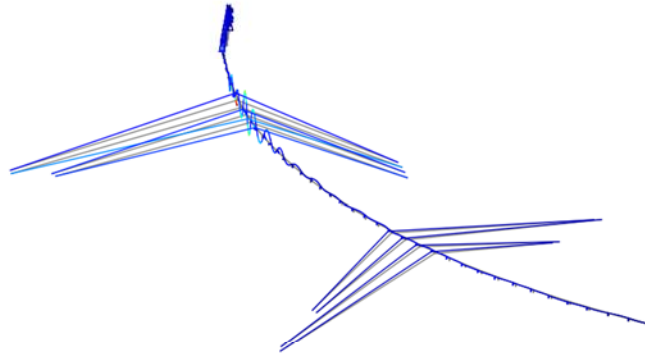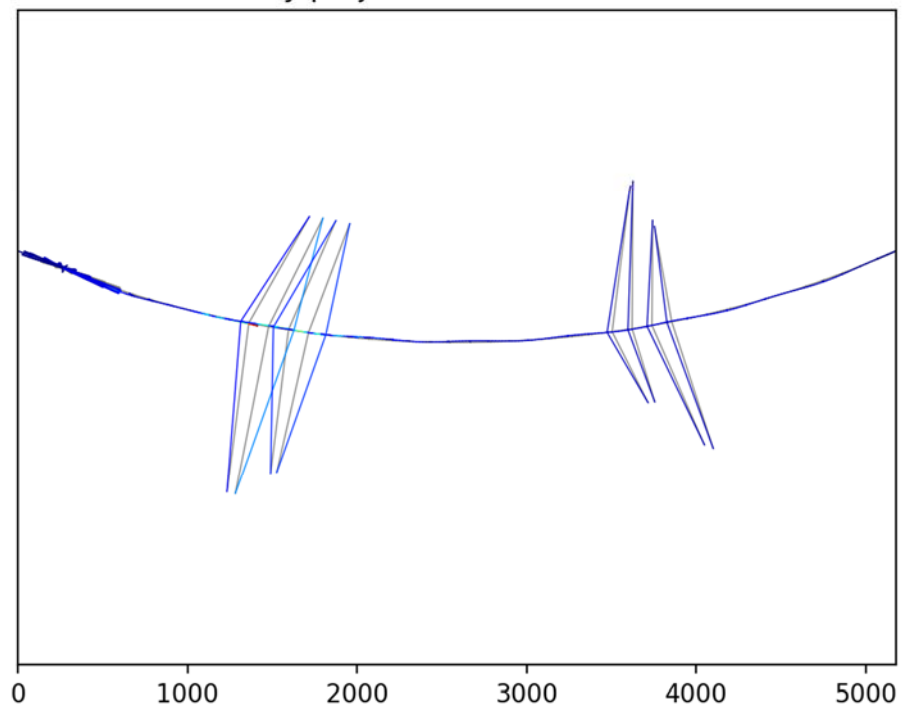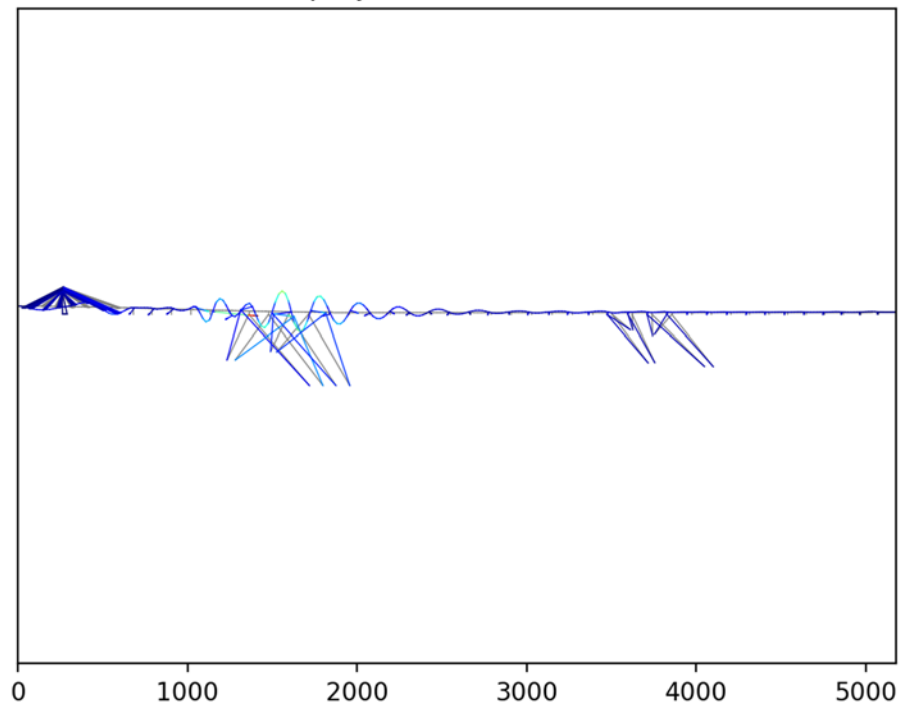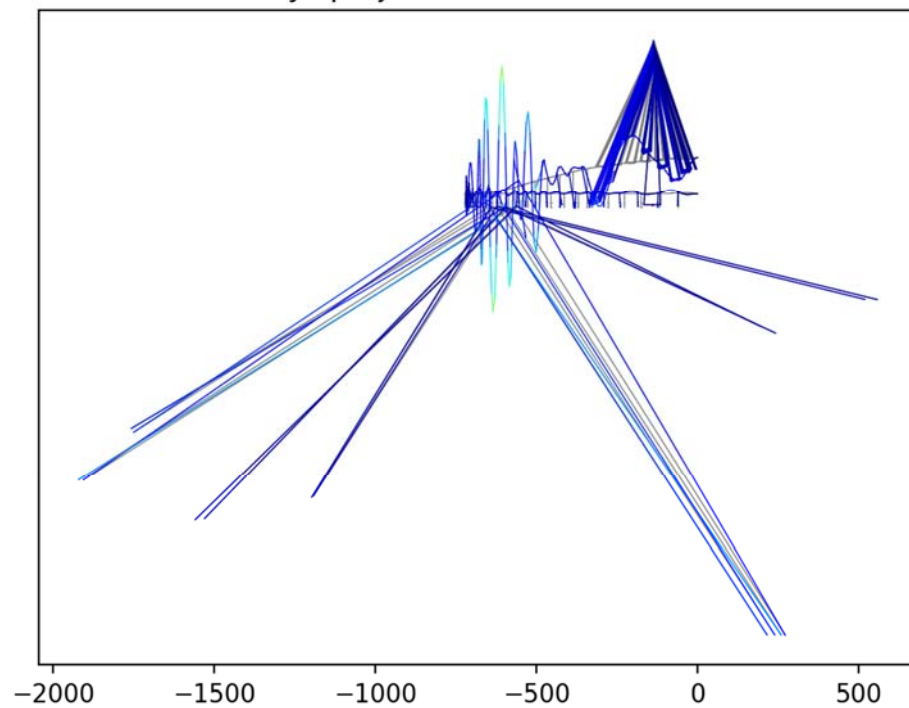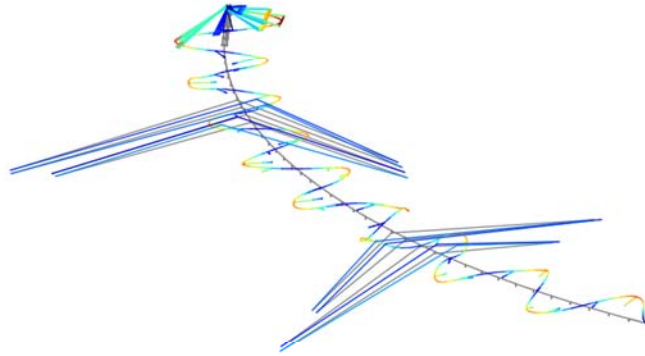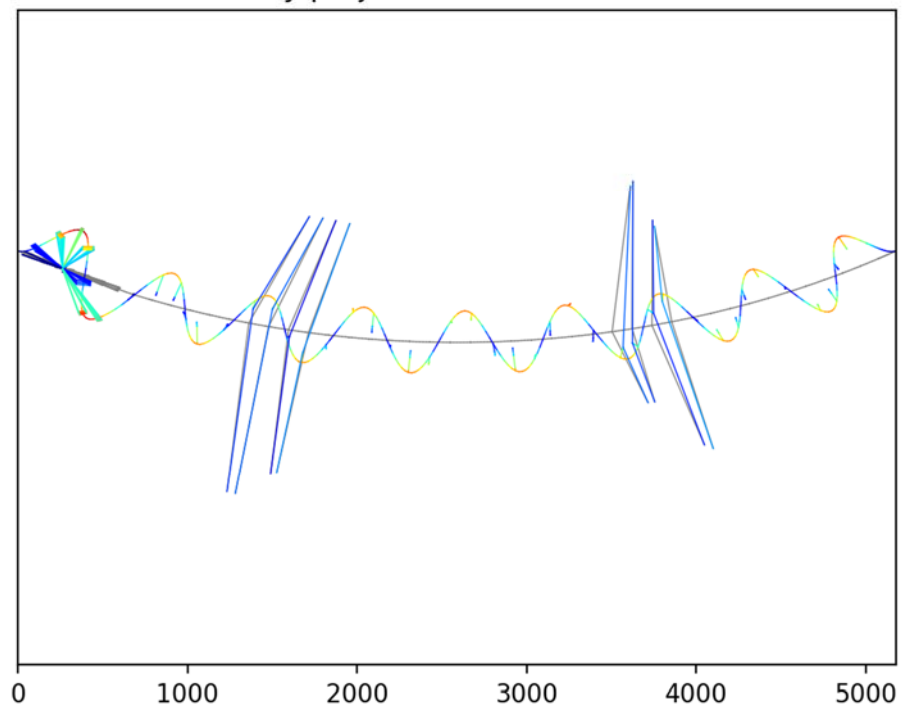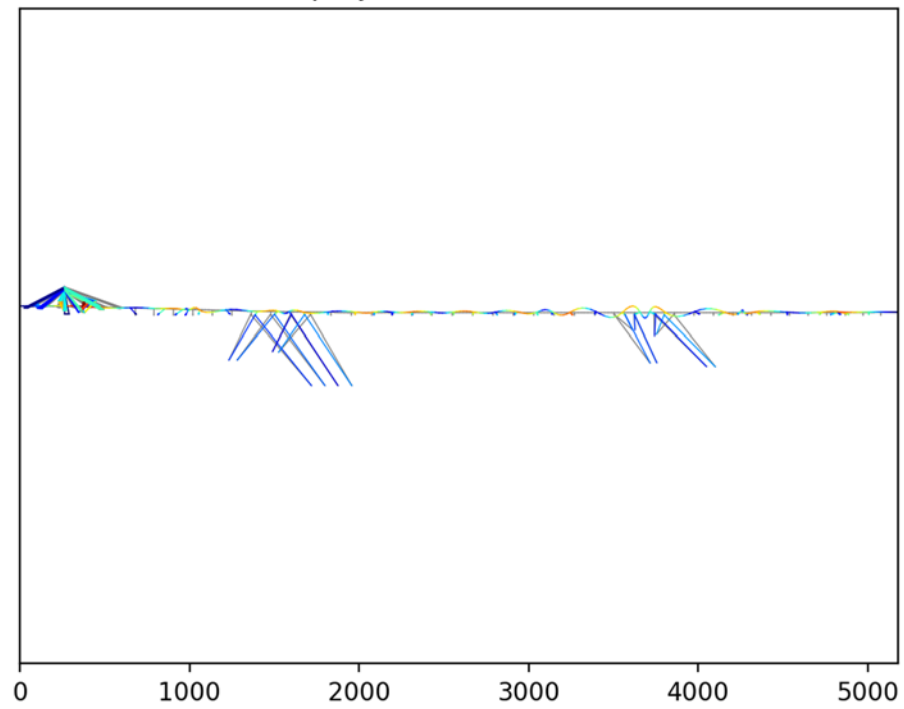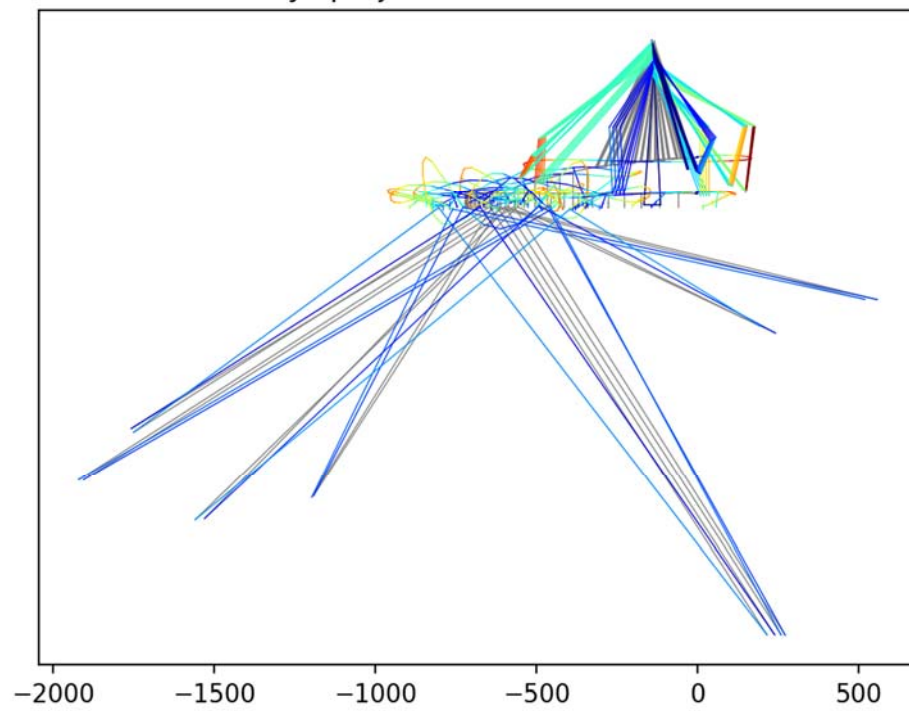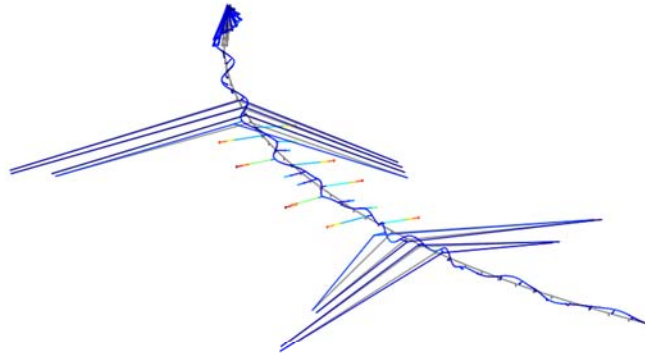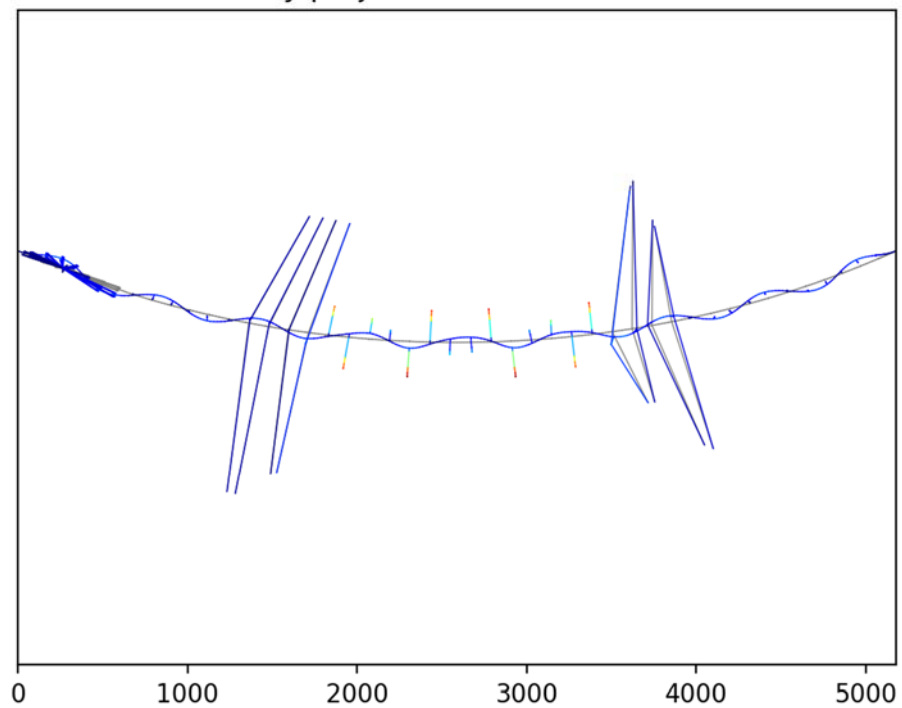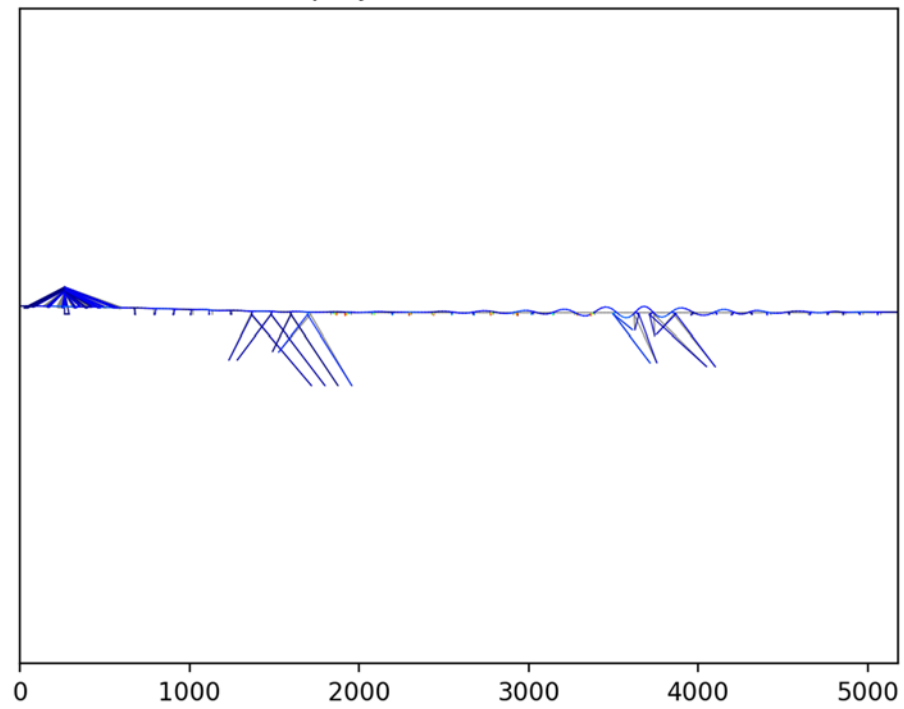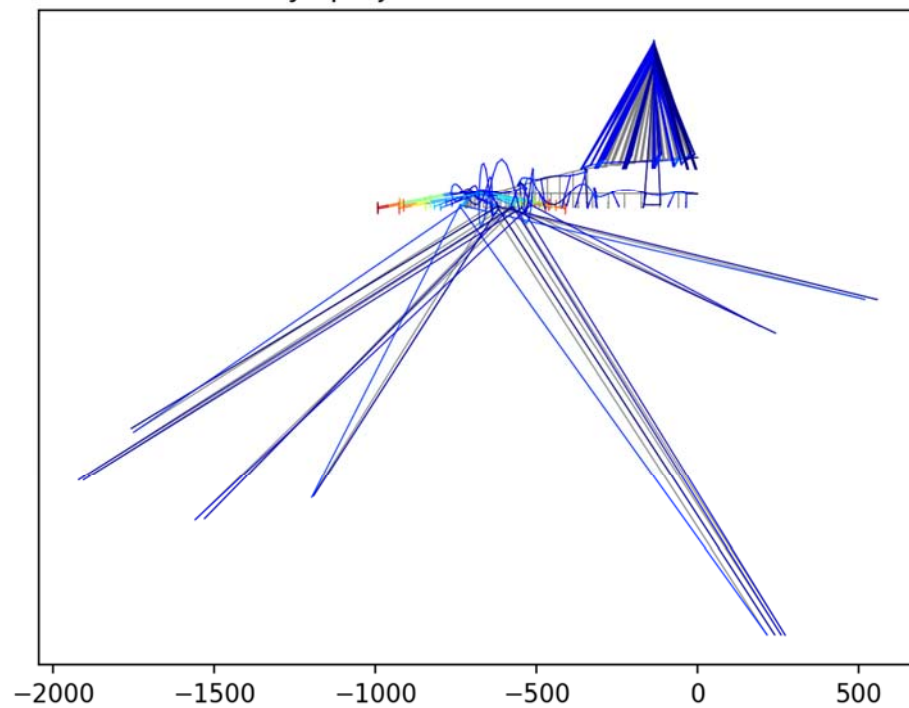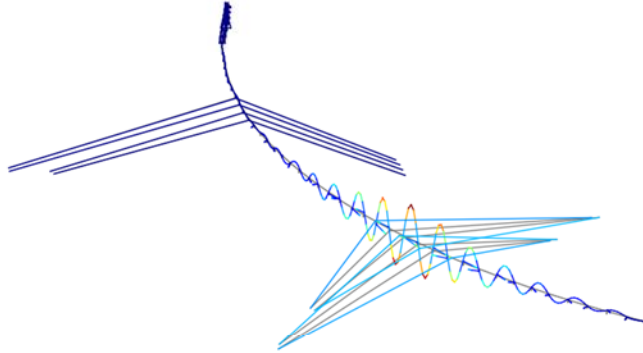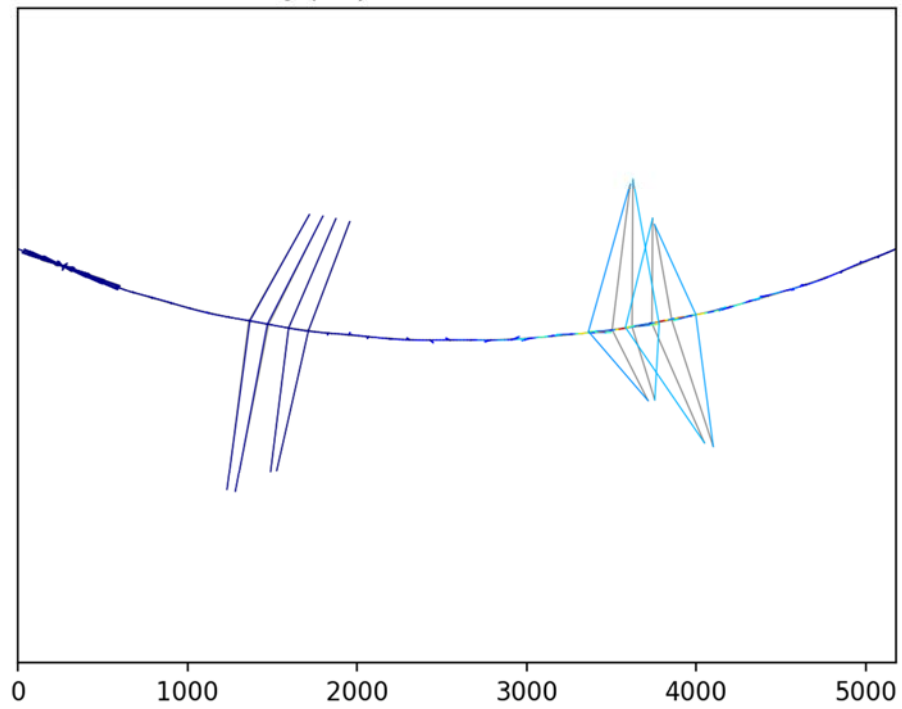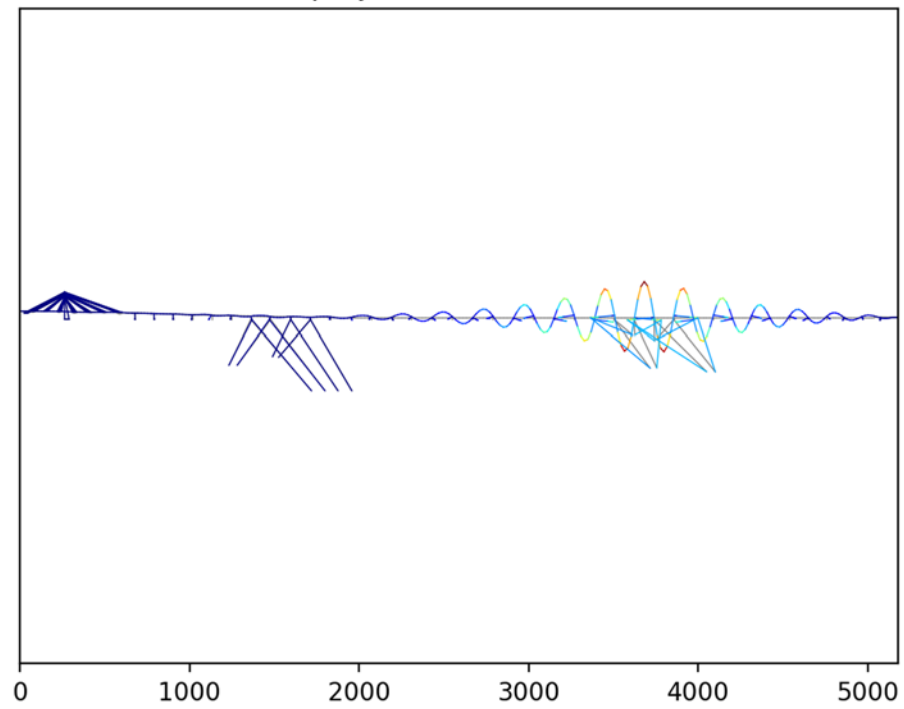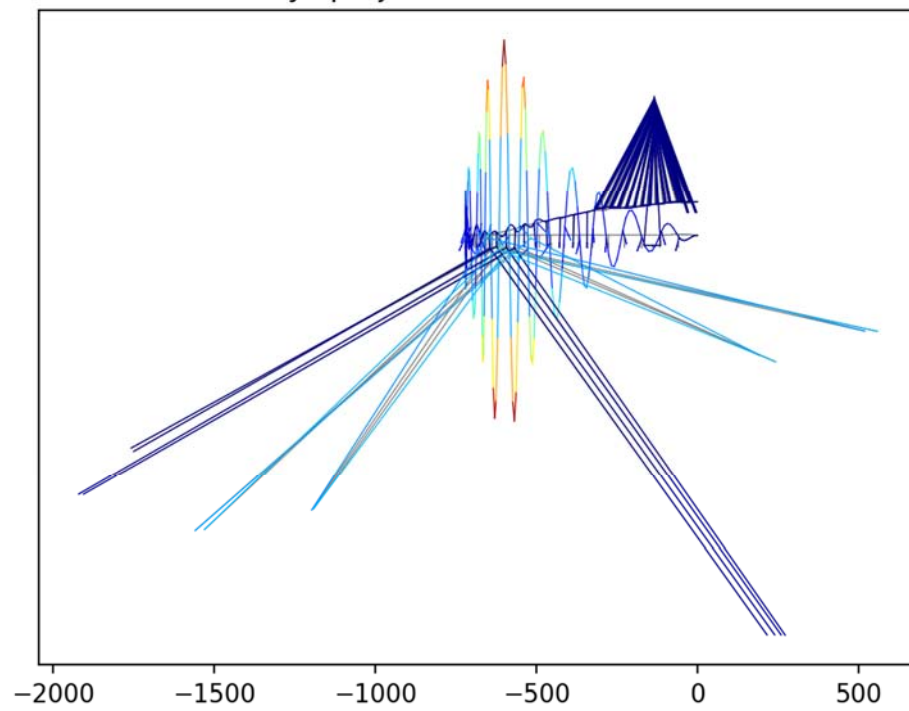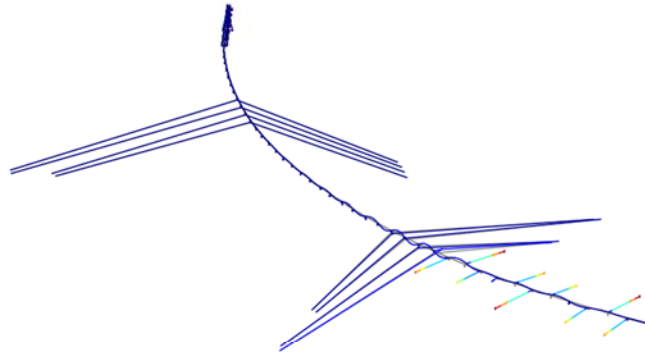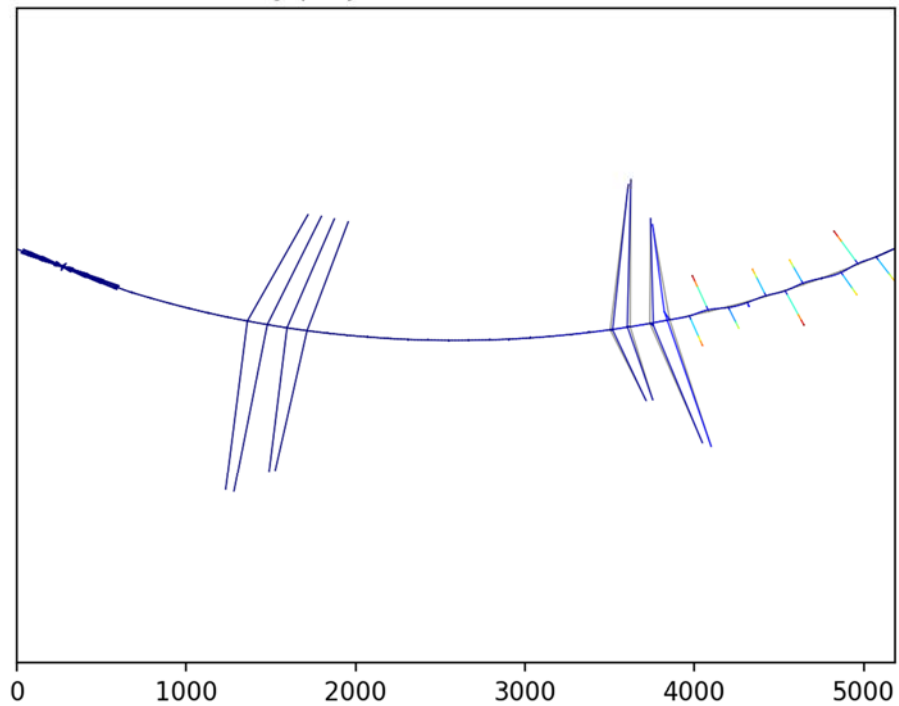
xz projection for mode 99
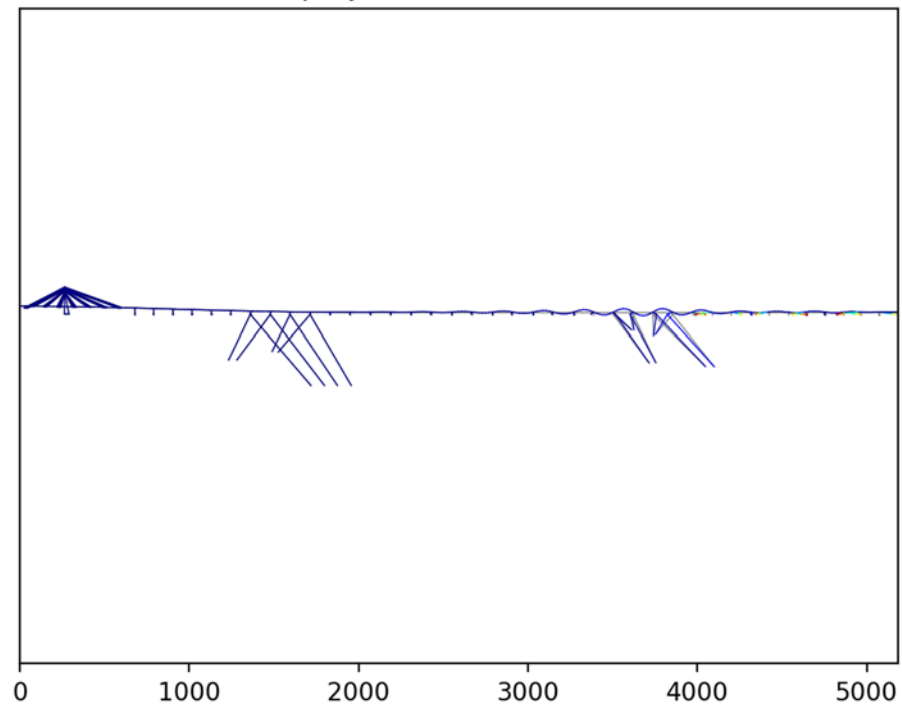

yz projection for mode 99
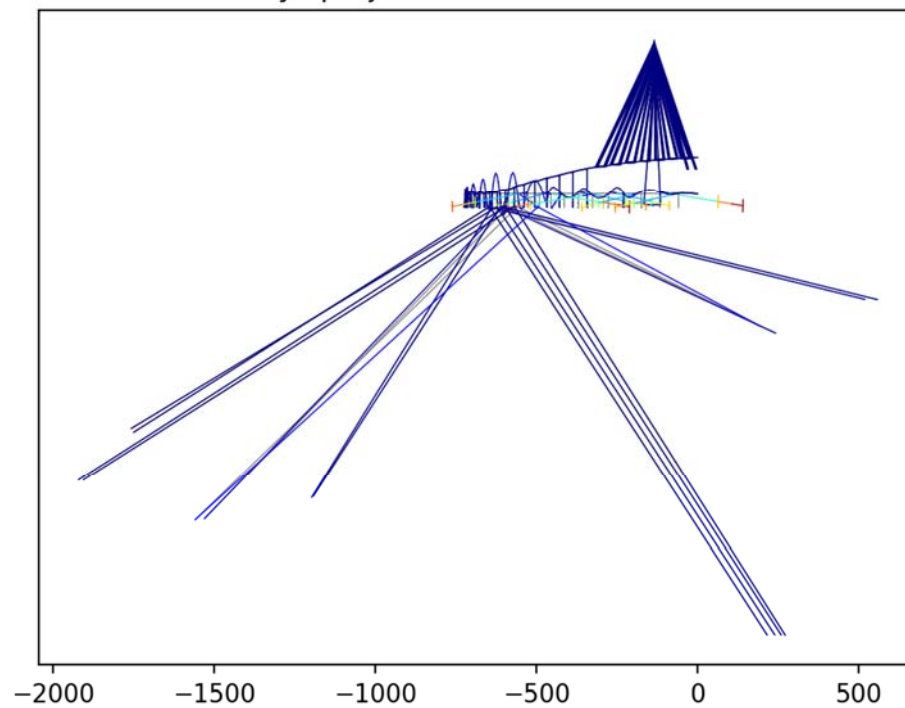
iso projection for mode 100

xy projection for mode 100

xz projection for mode 100

yz projection for mode 100

3   REFERENCES

[1]   R. B. Lehoucq, D. C. Sorensen og C. Yang, ARPACK USERS GUIDE: Solution of Large Scale Eigenvalue Problems by Implicitly Restarted Arnoldi Methods, SIAM, Philadelphia, PA, 1998.

[2]   Sofistik, Sofistik Basics, 2016.

[3]   SBJ-30-C3-NOR-90-RE-102-5 Appendix 5 - Modal analysis.

[4]   Olav Olsen, Olav Olsen interactive; Project Bjørnafjorden phase 5, Oslo.

[5]   Håndbok N400 , «Bruprosjektering,» Statens vegvesen Vegdirektoratet, 2015.

[6]   SBJ-32-C4-SVV-90-BA-001, «Design Basis Bjørnafjorden floating bridges,» Statens Vegvesen, 2018.

[7]   NS-EN 1993-1-1:2005+A1:2014+NA:2015, «Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings,» Standard Norge, 2005.

[8]   SBJ-30-C3-NOR-90-RE-102-4 Appendix 4 - Methods and theory.

[9]   SBJ-30-C3-NOR-90-RE-102-2 Appendix 2 - Sensitivity studies.

[10] DNV, WADAM User Manual, 2010.

[11] DNV, DNV-RP-C205 Environmental Conditions and Environmental loads, 2014.