

Contents

1. Introduction, purpose and scope of work	7
2. Static and dynamic displacements with elements of the methods of their analysis	10
2.1. Introduction	10
2.2. Displacements	10
2.3. Deformation	13
2.4. Loads occurring while surveying engineering structures	15
2.4.1. Vertical loads	16
2.4.2. Wind load	17
2.4.3. Thermal loads	19
2.5. An outline of mechanical system vibrations	22
2.5.1. Introduction	22
2.5.2. Simple harmonic motion	23
2.5.3. Damped oscillator	27
2.6. Digital signal	32
3. Control of the shape and location of engineering structures	41
3.1. Introduction	41
3.1.1. Periodic surveying and monitoring	41
3.1.2. Research-assisted design	43
3.2. Surveying of static displacements	44
3.2.1. Review of the requirements	44
3.2.2. Bridge structures	44
3.2.3. High structures	46
3.3. The meaning and scope of vibration measurement	47
3.3.1. Building requirements	47
3.3.2. Vibration surveys of buildings	49
3.3.3. Dynamic testing of bridge structures	51
3.3.4. Dynamic testing of high engineering structures	53

3.4. Methods for surveying displacement and vibration	55
3.4.1. Elements of metrology	55
3.4.2. Mechanical sensors	58
3.4.3. Electrical sensors	59
3.4.3.1. Inductive sensors	59
3.4.3.2. Strain gauges	61
3.4.3.3. Capacitive sensors	63
3.4.3.4. Photoelectric sensors	64
3.4.3.5. Lidar sensors	66
3.4.3.6. String potentiometers	66
3.4.3.7. Piezoelectric sensors	67
3.4.4. Surveying methods	67
3.4.4.1. Precision levels	68
3.4.4.2. Electronic total stations and scanners	69
3.4.4.3. Satellite positioning techniques	70
3.4.4.4. Photogrammetric methods	70
3.4.4.5. Other surveying instruments	71
4. Ground-based IBIS interferometric radar	73
4.1. Introduction	73
4.1.1. Basics of echolocation systems	73
4.1.2. Application of radars in displacement measuring	76
4.2. The construction and operation of the IBIS radar system	78
4.2.1. Application of the IBIS system	78
4.2.2. General description of the IBIS system elements	81
4.2.3. Characteristics of a signal used in the IBIS system	85
4.2.4. Characteristics of antennas used in the IBIS system	90
4.3. Principles for surveying and processing the results from the IBIS system	95
4.3.1. Surveying with IBIS-S CONTROLLER software	95
4.3.2. Processing data from IBIS-S in IBIS Data Viewer	101
4.3.3. Operation of the IBIS-L system	109
5. Influence of physical factors on the surveying accuracy of displacements	116
5.1. Physical factors determining the performance of the IBIS system	116
5.2. Influence of the atmosphere	121
5.3. Testing of radar range	126
5.3.1. Test in the free space	126
5.3.2. Test on a real structure	129
5.3.3. Assessing usable range of the IBIS-L system	134
5.4. Influence of the reflecting surface	137
5.4.1. Influence of the surface type on the results of observations – IBIS-S	137
5.4.2. Influence of the type of surface on the results of observations – IBIS-L	143

5.5. Testing of signal stability	146
5.6. Influence of characteristics of antennas	150
5.6.1. Verifying the actual characteristics of antennas	150
5.6.2. Influence of antenna selection on structure observation using the IBIS-S system	152
5.6.3. Influence of antenna selection on structure observation using the IBIS-L system	154
5.7. Testing of range resolution	157
6. Evaluating the accuracy of the IBIS interferometric radar	164
6.1. Introduction	164
6.2. Verification of the displacement survey accuracy using the IBIS-S system	165
6.2.1. Comparison with a laser interferometer	165
6.2.2. Surveys using a precision total station and reference reflector	169
6.2.3. Comparison with the laser vibrometer	174
6.3. Verification of the displacement survey accuracy using the IBIS-L system	180
6.4. Verifying the accuracy of determining vibration frequency	187
7. Surveying of static displacements and vibrations of bridge structures	192
7.1. Introduction	192
7.2. Test loads	195
7.2.1. Description of the test structure	195
7.2.2. Static load tests	196
7.2.3. Surveying dynamic test loads	200
7.3. Operational loads	207
7.4. Summary	213
8. Surveying of static displacement and vibration of high structures	214
8.1. Introduction	214
8.2. Static surveys	216
8.2.1. Industrial smokestacks	216
8.2.2. Telecommunications masts	221
8.2.3. Telecommunications towers	224
8.3. Dynamic surveys	228
8.3.1. Telecommunications masts	228
8.3.2. Industrial stacks	232
8.3.3. Shaft towers	236
8.4. Summary	239
9. Surveying of displacements of monolithic structures	240
9.1. Introduction	240
9.2. Planning of a survey	242

9.3. Initial surveys	245
9.4. Current surveys	249
9.5. Analysis of survey results	252
9.6. Conclusions	254
10. Summary	255
References	257