Contents

1 Introduction 1
1.1 General 1
1.2 Scope 2
1.3 Key features 3
2 Terms and definitions 4
3 Basic principles of earthquake-resistant design 6
3.1 General 6
3.1.1 Performance-based design philosophy 6
3.1.2 Performance requirement 8
3.1.2.1 Damage-limitation limit state 8
3.1.2.2 Collapse-prevention limit state 8
3.1.3 Seismic actions 9
3.1.3.1 Acceleration spectrum 9
3.1.2.2 Elastic-displacement spectrum 11
3.1.4 Equivalent damping for hysteretic response 12
3.1.5 Design concept 13
3.1.5.1 Force-based design 13
3.1.5.2 Displacement-based design 15
3.2 The case of precasting 19
3.2.1 Performance-based design philosophy 19
3.2.2 Connections 20
3.2.3 Ductility properties of structures 21
3.2.4 Supports 24
3.2.5 Second-order effects 26
3.2.6 Cladding-panel connections 26
3.2.7 Shear failure 27
3.2.8 Design of diaphragms 27
3.2.9 Stability of beams supported on columns 28
3.2.10 Structural integrity of precast structures - Ties 29
3.3 Basic principles of conceptual design (to satisfy the fundamental requirements of collapse avoidance and damage limitation) 31
3.3.1 General 31
3.3.2 Basic principles of conceptual design 32
3.3.2.1 Structural simplicity 33
3.3.2.2 In-plan uniformity - regularity 33
3.3.2.3 Vertical uniformity - regularity 35
3.3.2.4 Bidirectional resistance, torsional resistance and stiffness 39

3.3.2.5 Effects of the contribution of infills, partitions and cladding (strong beam-weak column) 40
3.3.2.6 Adequacy of foundation 43

4 Precast-building systems 45
4.1 General 45

5 Frame systems 46
5.1 General 46
5.2 Frames with hinged beam-to-column connections and HCF (cantilevered-column system in ASCE 7-10) 46
5.2.1 Hinged beam-to-column connections for HCF 48
5.3 Frames with moment-resisting columns 58
5.3.1 General 58
5.3.2 Equivalent monolithic moment-resisting beam-to-column connection systems 65
5.3.2.1 System S1 65
5.3.2.2 System S2 73
5.3.2.3 System S3 78
5.3.2.4 System S4 83
5.3.2.5 System S5 87
5.3.2.6 System S6 91
5.3.2.7 System S7 95
5.3.3 General information on jointed systems (H1, H2 and H3) 99
5.3.4 Column-to-foundation connections 117
5.3.4.1 Socket foundation 118
5.3.4.2 Column-to-foundation connections with corrugated-metal ducts or steel sleeves 126
5.3.4.3 Column-to-foundation connections with anchor bolts 128
5.3.4.4 Column-to-foundation connections with steel base plates 129
5.3.4.5 Column-to-foundation connections with external mild-steel reinforcement 130
5.3.5 Beam-to-column connections 133
5.3.6 Column-to-column connections 136

6 Large-panel wall systems 139
6.1 General 139
6.2 Classification 139
6.3 Seismic behaviour and structural integrity or robustness 141
6.4 Possible mechanisms for dissipation of seismic energy 143

6.5 Load effects in large-panel connections 145
6.6 Configuration and structural behaviour of wet joints made with cast-in-situ concrete and loop reinforcements 147
6.7 Construction details for large-panel buildings with wet joints (concrete and reinforcement) 152
6.8 Configuration and structural behaviour of North American platform-framing connections 157
6.8.1 Horizontal connections 157
6.8.2 Vertical-shear wall-to-wall connections 159
6.8.3 Structural integrity 159
6.8.4 Further information about ties, based on Schultz, 1979 162
7 Wall-frame systems (dual systems) 165
7.1 General 165
7.2 Shear walls and moment frames in dual systems 165
7.3 Typical connections in structural wall systems 169
8 Floor-framing systems 173
8.1 General 173
8.2 Aspects of diaphragm behaviour in precast-floor systems 174
8.2.1 Diaphragms with topping 175
8.2.2 Floors without topping 177
8.2.3 Rigid versus flexible diaphragms 178
8.2.4 Internal diaphragm actions 179
8.2.5 Behaviour of precast-floor diaphragms under seismic action 181
8.3 Displacement incompatibility issues between lateral-resisting systems and precast-floor diaphragms 183
8.3.1 General 183
8.3.2 Strength enhancement of beams due to interaction with precast floors 186
8.3.3 Other examples of displacement incompatibility effects 187
8.3.4 Design guidelines for hollow-core-floor-to-lateral-resisting-system connections 191
8.3.5 Support length of precast-floor units for prevention of unseating in seismic situations 193
8.4 Controlling and reducing damage to floor diaphragm 199
8.4.1 Jointed, 'articulated' floor system 199
8.4.2 Top-hinge and slotted solution 201
9 Double-wall systems 203
9.1 General 203

9.2 On-site construction technique 204
9.3 Ductile behaviour 205
9.4 Numerical models for structural analysis 205
9.5 Structural connections and other structural details 206

10 Precast-cell systems 213
10.1 General 213
10.2 Classification 214
10.3 Construction aspects 216
10.4 Connections 219
10.5 Box structures in the United States 222

Appendix A: Structural ductility of precast-frame systems 223
A.1 Local ductility 223
A.2 Global ductility 226
A.3 One-storey frames 227
A.4 Other types of ductility 229

Appendix B: Selected technical data 230
B.1 General 230
B.2 Ductility-dissipation relation 231
B.3 Standard values 232

Appendix C: Design examples of one-storey industrial building 234
C.1 General 234
C.1.1 Prototype one-storey industrial building 234
C.1.2 Seismic hazard and spectra 236
C.2 Iterative force-based design (FBD) of one-storey industrial building at ULS (collapse prevention) 238
C.2.1 Step 1: Evaluating initial period T_i 238
C.2.2 Step 2: Calculating spectral ordinates and base shear 239
C.2.3 Step 3: Evaluating displacement demand 240
C.2.4 Step 4: Checking ultimate limit state caused by *P-Δ* effects 241
C.2.5 Step 5: Designing structural elements and critical sections 243
C.2.6 Step 6: Checking initial assumptions of stiffness, period, displacement demand and oft-neglected *q* factor 243
C.2.7 Step 7: Evaluating actual performance 245
C.2.8 Step 8: Further increase of base shear capacity (column stiffness) until column meets design requirements 247
C.3 Iterative force-based design (FBD) of one-storey industrial building at

SLS (damage limitation) 250
C.4 Closed-form force-based design (CFBD) of one-storey industrial building for ULS (collapse prevention) 252
C.4.1 Step 1: Determining yield deflection of structure 252
C.4.2 Step 2: Determining feasible design solutions using strength-stiffness compatibility-domain curve 253
C.4.3 Step 3: Determining design seismic base shear and verifying sensitivity coefficient 254
C.5 Closed-form force-based design (CFBD) of one-storey industrial building for SLS (damage limitation) 256
C.6 Displacement-based design (DBD) of one-storey industrial building for ULS (collapse prevention) 258
C.6.1 Step 1: Equivalent SDOF system 258
C.6.2 Step 2: Setting ultimate (target) displacement and calculating yielding displacement, ductility and equivalent viscous damping 259
C.6.3 Step 3: Entering displacement spectrum and evaluating effective period and stiffness (secant to target displacement) 260
C.7 Displacement-based design (DBD) of one-storey industrial building for SLS (damage limitation) 262
C.7.1 Step 1: Equivalent SDOF building 262
C.7.2 Step 2: Setting ultimate (target) displacement and calculating yielding displacement, ductility and equivalent viscous damping 262
C.7.3 Step 3: Entering displacement spectrum and evaluating effective period and stiffness (secant to target displacement) 263
C.8 Comparison of FBD, closed-form FBD and DBD 264
References 265