

**UNIVERSITY COLLEGE LONDON**

**EXAMINATION FOR INTERNAL STUDENTS**

**MODULE CODE** : CEGE 0021

**MODULE NAME** : Civil Engineering in Practice

**DATE** : 21 January 2021

**TIME** : 10.00

**TIME ALLOWED** : 3 Hours

**TURN OVER**

## CEGE0021: CIVIL ENGINEERING IN PRACTICE

BEng/MEng

Course Examination – 2020/2021

*Time allowed: 3 hours*

- Answer **ALL** questions.
- All Questions carry equal marks.
- Tables showing the dimensions and properties of steel Universal Beams and Columns can be found in Appendix A.
- Some design information not included in EN1993 can be found in Appendix B.

Q1. (a) Computers are commonly used for both design and drawings but based on your experience how useful are they? [5 Marks]

(b) Determine the suitability in shear, bending and deflection of a  $406 \times 178 \times 60$  UB in S275 to support the loading shown in Figure Q1 assuming the beam is fully laterally restrained. [15 Marks]

(c) Recheck the suitability of the UB section assuming it is laterally and torsionally restrained at supports and at load points only. List any further assumptions.

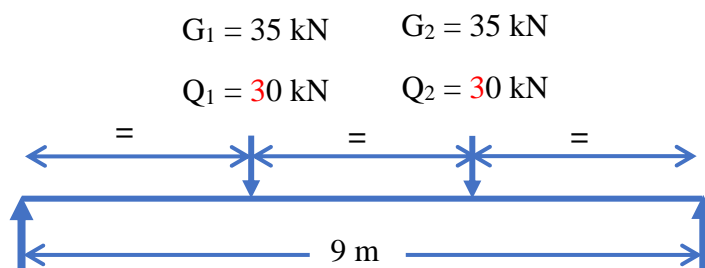
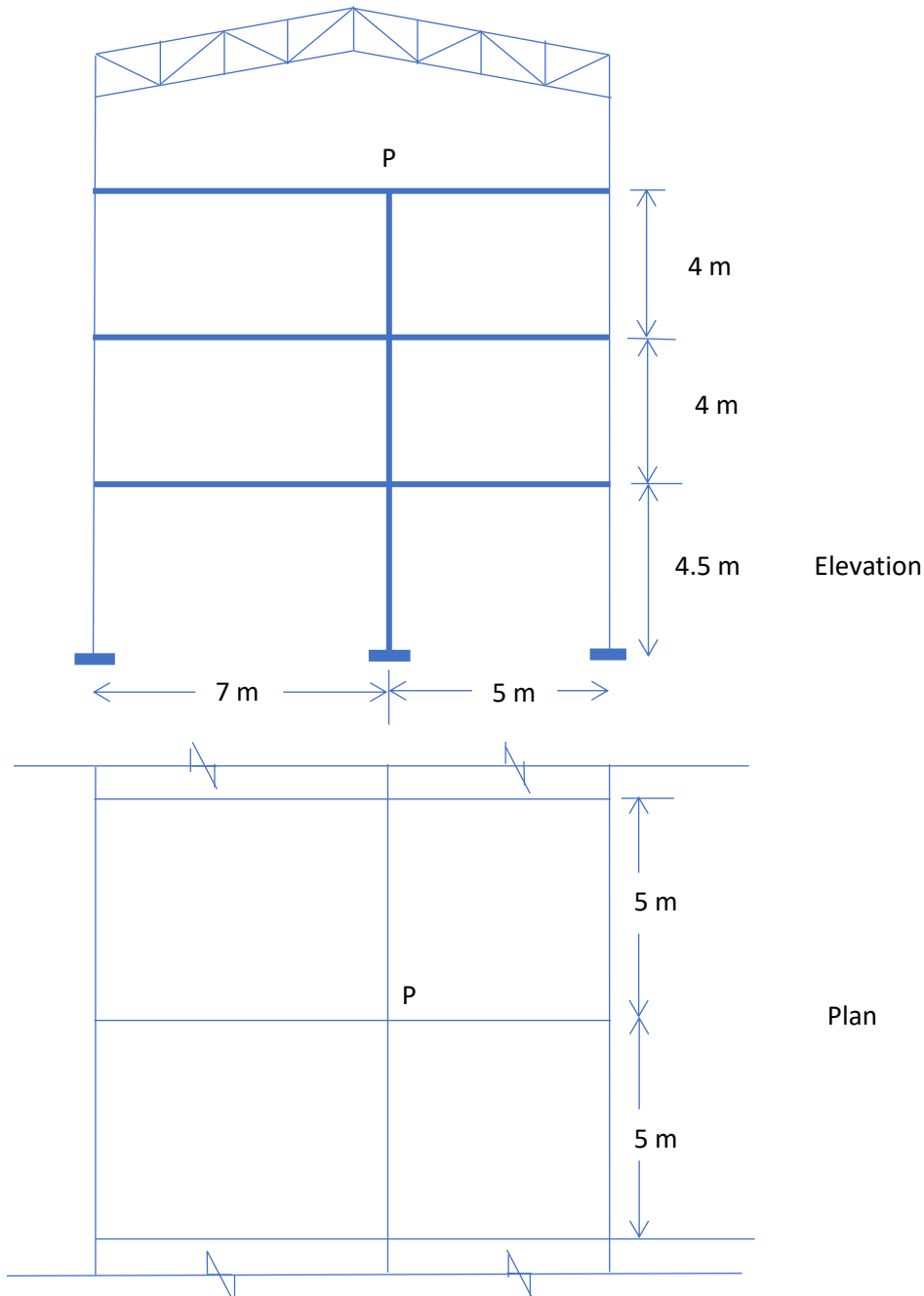


FIGURE Q1

[5 Marks]

**TURN OVER**

- Q2. (a) FIGURE Q2 shows an elevation and part plan of a steel structure of simple construction. Note that the roof is supported by the external columns. Check the suitability of a  $203 \times 203 \times 60$  UC in S275 steel for column P by considering the Ground to 1<sup>st</sup> floor length. Assume all the floors support characteristic permanent (including self weight of slab) and imposed floor loads of  $4 \text{ kN/m}^2$  and  $3.5 \text{ kN/m}^2$  respectively. List any assumptions.



**FIGURE Q2**

**[20 Marks]**

- (b) Describe how the verification procedure for the column would change if the frame was of continuous construction. **[5 marks]**

**[END OF PAPER]**

## **APPENDIX A**

- **Dimensions and properties of steel UB and UC section**

## **APPENDIX B**

### **DESIGN DATA**

- **Columns in simple construction**
- **Classification of sections subject to combined axial load and bending**
- **Elastic critical moment**
- **Deflection**

# APPENDIX A

**Table B1** Dimensions and properties of steel universal beams (structural sections to BS 4: Part 1 and BS 4848: Part 4)

| Serial size | Designation | Dimensions       |                  |               |             |                       | Properties               |                       |                    |                                    |                                    |                                    |                                    |                                    |                                    |        |       |                      |                      |                      |      |      |
|-------------|-------------|------------------|------------------|---------------|-------------|-----------------------|--------------------------|-----------------------|--------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|--------|-------|----------------------|----------------------|----------------------|------|------|
|             |             | Depth of section | Width of section | Web thickness | Root radius | Depth between fillets | Ratio for local buckling | Second moment of area | Radius of gyration | Elastic modulus                    | Plastic modulus                    | Buckling torsional index           | Warping constant                   | Torsional area of section          |                                    |        |       |                      |                      |                      |      |      |
|             |             | D (mm)           | B (mm)           | t (mm)        | T (mm)      | r (mm)                | d (mm)                   | Flange b/T            | Web d/c            | A <sub>xx</sub> (cm <sup>4</sup> ) | A <sub>yy</sub> (cm <sup>4</sup> ) | A <sub>xx</sub> (cm <sup>3</sup> ) | A <sub>yy</sub> (cm <sup>3</sup> ) | A <sub>xx</sub> (cm <sup>3</sup> ) | A <sub>yy</sub> (cm <sup>3</sup> ) | u      | x     | H (dm <sup>4</sup> ) | J (cm <sup>4</sup> ) | A (cm <sup>2</sup> ) |      |      |
| 914x419     | 388         | 920.5            | 420.5            | 21.5          | 36.6        | 24.1                  | 799.1                    | 5.74                  | 37.2               | 719 000                            | 45 400                             | 38.1                               | 9.58                               | 15 600                             | 2 160                              | 17 700 | 3 340 | 0.884                | 26.7                 | 88.7                 | 1730 | 494  |
|             | 343         | 911.4            | 418.5            | 19.4          | 32.0        | 24.1                  | 799.1                    | 6.54                  | 41.2               | 625 000                            | 39 200                             | 37.8                               | 9.46                               | 13 700                             | 1870                               | 15 500 | 2 890 | 0.883                | 30.1                 | 75.7                 | 1190 | 437  |
|             | 289         | 926.6            | 307.8            | 19.6          | 32.0        | 19.1                  | 824.5                    | 4.81                  | 42.1               | 505 000                            | 15 600                             | 37.0                               | 6.51                               | 10 900                             | 1010                               | 12 600 | 1 600 | 0.867                | 31.9                 | 31.2                 | 929  | 369  |
|             | 253         | 918.5            | 305.5            | 17.3          | 27.9        | 19.1                  | 824.5                    | 5.47                  | 47.7               | 437 000                            | 13 300                             | 36.8                               | 6.42                               | 9 510                              | 872                                | 10 900 | 1 370 | 0.866                | 36.2                 | 26.4                 | 627  | 323  |
|             | 224         | 910.3            | 304.1            | 15.9          | 23.9        | 19.1                  | 824.5                    | 6.36                  | 51.9               | 376 000                            | 11 200                             | 36.3                               | 6.27                               | 8 260                              | 738                                | 9 520  | 1 160 | 0.861                | 41.3                 | 22.0                 | 421  | 285  |
| 838x292     | 201         | 903.0            | 303.4            | 15.2          | 20.2        | 19.1                  | 824.5                    | 7.51                  | 54.2               | 326 000                            | 9 430                              | 35.6                               | 6.06                               | 7 210                              | 621                                | 8 360  | 983   | 0.853                | 46.8                 | 18.4                 | 293  | 256  |
|             | 226         | 850.9            | 293.8            | 16.1          | 26.8        | 17.8                  | 761.7                    | 5.48                  | 47.3               | 340 000                            | 11 400                             | 34.3                               | 6.27                               | 7 990                              | 773                                | 9 160  | 1 210 | 0.87                 | 35.0                 | 19.3                 | 514  | 289  |
|             | 194         | 840.7            | 292.4            | 14.7          | 21.7        | 17.8                  | 761.7                    | 6.74                  | 51.8               | 279 000                            | 9 070                              | 33.1                               | 5.90                               | 6 550                              | 620                                | 7 650  | 974   | 0.862                | 41.6                 | 15.2                 | 307  | 247  |
|             | 176         | 834.9            | 291.6            | 14.0          | 18.8        | 17.8                  | 761.7                    | 7.76                  | 54.4               | 246 000                            | 7 790                              | 33.1                               | 5.90                               | 5 890                              | 534                                | 6 810  | 842   | 0.856                | 46.5                 | 13.0                 | 222  | 224  |
|             | 197         | 769.6            | 266.7            | 15.6          | 25.4        | 16.5                  | 685.8                    | 5.28                  | 44.0               | 240 000                            | 8 170                              | 30.9                               | 5.71                               | 6 230                              | 610                                | 7 170  | 959   | 0.869                | 33.2                 | 11.3                 | 405  | 251  |
| 762x267     | 173         | 762.0            | 266.7            | 14.3          | 21.6        | 16.5                  | 685.8                    | 6.17                  | 48.0               | 205 000                            | 6 850                              | 30.5                               | 5.57                               | 5 390                              | 513                                | 6 200  | 807   | 0.864                | 38.1                 | 9.38                 | 267  | 220  |
|             | 147         | 753.9            | 265.3            | 12.9          | 17.5        | 16.5                  | 685.8                    | 7.58                  | 53.2               | 169 000                            | 5 870                              | 30.0                               | 5.39                               | 4 480                              | 412                                | 5 170  | 649   | 0.857                | 45.1                 | 7.41                 | 161  | 188  |
|             | 170         | 692.9            | 255.8            | 14.5          | 23.7        | 15.2                  | 615.1                    | 5.40                  | 42.4               | 170 000                            | 6 620                              | 28.0                               | 5.33                               | 4 910                              | 518                                | 5 620  | 810   | 0.871                | 31.8                 | 7.41                 | 307  | 217  |
|             | 152         | 687.6            | 254.5            | 13.2          | 21.0        | 15.2                  | 615.1                    | 6.06                  | 46.6               | 150 000                            | 5 780                              | 27.8                               | 5.46                               | 4 370                              | 454                                | 5 000  | 710   | 0.873                | 35.5                 | 6.42                 | 219  | 194  |
|             | 140         | 683.5            | 253.7            | 12.4          | 19.0        | 15.2                  | 615.1                    | 6.68                  | 49.6               | 136 000                            | 5 180                              | 27.6                               | 5.38                               | 3 990                              | 408                                | 4 560  | 638   | 0.868                | 38.7                 | 5.72                 | 169  | 179  |
| 610x305     | 125         | 677.9            | 253.0            | 11.7          | 16.2        | 15.2                  | 615.1                    | 7.81                  | 52.6               | 118 000                            | 4 380                              | 27.2                               | 5.24                               | 3 480                              | 346                                | 4 000  | 542   | 0.862                | 43.9                 | 4.79                 | 116  | 160  |
|             | 238         | 633.0            | 311.5            | 18.6          | 31.4        | 16.5                  | 537.2                    | 4.96                  | 28.9               | 208 000                            | 15 800                             | 26.1                               | 7.22                               | 6 560                              | 1 020                              | 7 460  | 1 570 | 0.886                | 21.1                 | 14.3                 | 788  | 304  |
|             | 179         | 617.5            | 307.0            | 14.1          | 23.6        | 16.5                  | 537.2                    | 6.50                  | 38.1               | 152 000                            | 11 400                             | 25.8                               | 7.08                               | 4 910                              | 743                                | 5 520  | 1 140 | 0.886                | 27.5                 | 10.1                 | 341  | 228  |
|             | 149         | 609.6            | 304.8            | 11.9          | 19.7        | 16.5                  | 537.2                    | 7.74                  | 45.1               | 125 000                            | 9 300                              | 25.6                               | 6.99                               | 4 090                              | 610                                | 4 570  | 937   | 0.886                | 32.5                 | 8.09                 | 200  | 190  |
|             | 140         | 617.0            | 230.1            | 13.1          | 22.1        | 12.7                  | 547.3                    | 5.21                  | 41.8               | 112 000                            | 4 510                              | 25.0                               | 5.03                               | 3 630                              | 392                                | 4 150  | 612   | 0.875                | 30.5                 | 3.99                 | 217  | 178  |
| 533x210     | 125         | 611.9            | 229.0            | 11.9          | 19.6        | 12.7                  | 547.3                    | 5.84                  | 46.0               | 98 600                             | 3 930                              | 24.9                               | 4.96                               | 3 220                              | 344                                | 3 680  | 536   | 0.873                | 34.0                 | 3.45                 | 155  | 160  |
|             | 113         | 607.3            | 228.2            | 11.2          | 17.3        | 12.7                  | 547.3                    | 6.60                  | 48.9               | 87 400                             | 3 440                              | 24.6                               | 4.88                               | 2 880                              | 301                                | 3 290  | 470   | 0.87                 | 37.9                 | 2.99                 | 112  | 144  |
|             | 101         | 602.2            | 227.6            | 10.6          | 14.8        | 12.7                  | 547.3                    | 7.69                  | 51.6               | 75 700                             | 2 910                              | 24.2                               | 4.75                               | 2 510                              | 256                                | 2 880  | 400   | 0.863                | 43.0                 | 2.51                 | 77.2 | 129  |
|             | 109         | 539.5            | 210.7            | 11.6          | 18.8        | 12.7                  | 476.5                    | 5.67                  | 47.2               | 66 700                             | 2 940                              | 21.9                               | 4.60                               | 2 470                              | 279                                | 2 820  | 435   | 0.875                | 30.9                 | 1.99                 | 126  | 139  |
|             | 101         | 536.7            | 210.1            | 10.9          | 17.4        | 12.7                  | 476.5                    | 6.04                  | 43.7               | 61 700                             | 2 690                              | 21.8                               | 4.56                               | 2 300                              | 257                                | 2 620  | 400   | 0.874                | 33.1                 | 1.82                 | 102  | 129  |
| 457x191     | 92          | 533.1            | 209.3            | 10.2          | 15.6        | 12.7                  | 476.5                    | 6.71                  | 46.7               | 55 400                             | 2 390                              | 21.7                               | 4.51                               | 2 080                              | 229                                | 2 370  | 356   | 0.872                | 36.4                 | 1.60                 | 76.2 | 118  |
|             | 82          | 528.3            | 208.7            | 9.6           | 13.2        | 12.7                  | 476.5                    | 7.91                  | 49.6               | 47 500                             | 2 010                              | 21.3                               | 4.38                               | 1 800                              | 192                                | 2 060  | 300   | 0.865                | 41.6                 | 1.33                 | 51.3 | 104  |
|             | 98          | 467.4            | 192.8            | 11.4          | 19.6        | 10.2                  | 407.9                    | 4.92                  | 35.8               | 45 700                             | 2 340                              | 19.1                               | 4.33                               | 1 960                              | 243                                | 2 230  | 378   | 0.88                 | 25.8                 | 1.17                 | 121  | 125  |
|             | 89          | 463.6            | 192.0            | 10.6          | 17.7        | 10.2                  | 407.9                    | 5.42                  | 38.5               | 41 000                             | 2 090                              | 19.0                               | 4.28                               | 1 770                              | 217                                | 2 010  | 338   | 0.879                | 28.3                 | 1.04                 | 90.5 | 114  |
|             | 82          | 460.2            | 191.3            | 9.9           | 16.0        | 10.2                  | 407.9                    | 5.98                  | 41.2               | 37 100                             | 1 870                              | 18.8                               | 4.23                               | 1 630                              | 196                                | 1 830  | 304   | 0.877                | 30.9                 | 0.923                | 69.2 | 105  |
| 457x152     | 74          | 457.2            | 190.5            | 9.1           | 14.5        | 10.2                  | 407.9                    | 6.57                  | 44.8               | 33 400                             | 1 670                              | 18.7                               | 4.19                               | 1 460                              | 175                                | 1 660  | 272   | 0.876                | 33.9                 | 0.819                | 52.0 | 95.0 |
|             | 67          | 453.6            | 189.9            | 8.5           | 12.7        | 10.2                  | 407.9                    | 7.48                  | 48.0               | 29 400                             | 1 450                              | 18.5                               | 4.12                               | 1 300                              | 153                                | 1 470  | 237   | 0.873                | 37.9                 | 0.706                | 37.1 | 85.4 |
|             | 82          | 465.1            | 153.5            | 10.7          | 18.9        | 10.2                  | 407.0                    | 4.06                  | 38.0               | 29 400                             | 1 140                              | 18.6                               | 4.06                               | 1 160                              | 149                                | 1 300  | 235   | 0.872                | 27.3                 | 0.569                | 89.3 | 104  |
|             | 74          | 461.3            | 152.7            | 9.9           | 17.0        | 10.2                  | 407.0                    | 4.49                  | 41.1               | 32 400                             | 1 010                              | 18.5                               | 3.26                               | 1 410                              | 133                                | 1 620  | 209   | 0.87                 | 30.0                 | 0.499                | 66.6 | 95.0 |
|             | 67          | 457.2            | 151.9            | 9.1           | 15.0        | 10.2                  | 407.0                    | 5.06                  | 44.7               | 28 600                             | 878                                | 18.3                               | 3.21                               | 1 250                              | 116                                | 1 440  | 182   | 0.867                | 33.6                 | 0.429                | 47.5 | 85.4 |
| 406x178     | 60          | 454.7            | 152.9            | 8.0           | 13.3        | 10.2                  | 407.7                    | 5.75                  | 51.0               | 25 500                             | 794                                | 18.3                               | 3.23                               | 1 120                              | 104                                | 1 280  | 163   | 0.869                | 37.5                 | 0.387                | 33.6 | 75.9 |
|             | 52          | 449.8            | 152.4            | 7.6           | 10.9        | 10.2                  | 407.7                    | 6.99                  | 53.6               | 21 300                             | 685                                | 17.9                               | 3.11                               | 949                                | 84.6                               | 1 090  | 133   | 0.859                | 43.9                 | 0.311                | 21.3 | 66.5 |
|             | 74          | 412.8            | 179.7            | 9.7           | 16.0        | 10.2                  | 360.5                    | 5.62                  | 37.2               | 27 300                             | 1 540                              | 17.0                               | 4.03                               | 1 320                              | 172                                | 1 500  | 267   | 0.881                | 27.6                 | 0.608                | 63.0 | 95.0 |
|             | 67          | 409.4            | 178.8            | 8.8           | 14.3        | 10.2                  | 360.5                    | 6.25                  | 41.0               | 24 500                             | 1 360                              | 16.9                               | 4.00                               | 1 190                              | 135                                | 1 350  | 237   | 0.88                 | 30.5                 | 0.533                | 46.0 | 85.5 |
|             | 60          | 406.4            | 177.8            | 7.8           | 12.8        | 10.2                  | 360.5                    | 6.95                  | 46.2               | 21 500                             | 1 200                              | 16.8                               | 3.97                               | 1 060                              | 135                                | 1 190  | 208   | 0.88                 | 33.9                 | 0.464                | 32.9 | 76.0 |
| 406x140     | 54          | 402.6            | 177.6            | 7.6           | 10.9        | 10.2                  | 360.5                    | 8.15                  | 47.4               | 18 600                             | 1 020                              | 16.5                               | 3.85                               | 925                                | 114                                | 1 050  | 177   | 0.872                | 38.5                 | 0.39                 | 22.7 | 68.4 |
|             | 46          | 402.3            | 142.4            | 6.9           | 11.2        | 10.2                  | 359.7                    | 6.36                  | 52.1               | 15 600                             | 539                                | 16.3                               | 3.02                               | 778                                | 75.7                               | 888    | 118   | 0.87                 | 38.8                 | 0.206                | 19.2 | 59.0 |
|             | 39          | 397.3            | 141.8            | 6.3           | 8.6         | 10.2                  | 359.7                    | 8.24                  | 57.1               | 12 500                             | 411                                | 15.9                               | 2.89                               | 627                                | 58.0                               | 721    | 91.1  | 0.859                | 47.4                 | 0.155                | 10.6 | 49.4 |
|             | 57          | 364.0            | 173.2            | 9.1           | 15.7        | 10.2                  | 312.3                    | 5.52                  | 34.3               | 19 500                             | 1 360                              | 15.1                               | 3.99                               | 1 070                              | 157                                | 1 210  | 243   | 0.887                | 24.4                 | 0.413                | 55.5 | 85.4 |
|             | 51          | 356.6            | 172.1            | 8.0           | 13.0        | 10.2                  | 312.3                    | 6.62                  | 39.0               | 16 100                             | 1 110                              | 14.9                               | 3.92                               | 896                                | 129                                | 1 010  | 199   | 0.884                | 28.9                 | 0.331                | 33.1 | 72.2 |
| 356x127     | 45          | 352.0            | 171.0            | 6.9           | 9.7         | 10.2                  | 312.3                    | 7.46                  | 42.8               | 14 200                             | 968                                | 14.8                               | 3.87                               | 796                                | 113                                | 895    | 174   | 0.882                | 32.2                 | 0.286                | 23.6 | 64.6 |
|             | 39          | 352.8            | 126.0            | 6.5           | 10.7        | 10.2                  | 312.3                    | 8.81                  | 45.3               | 12 100                             | 812                                | 14.6                               | 3.78                               | 687                                | 95.0                               | 774    | 147   | 0.875                | 36.9                 | 0.238                | 15.7 | 57.0 |
|             | 33          | 348.5            | 125.4            | 5.9           | 8.5         | 10.2                  | 311.2                    | 5.89                  | 47.9               | 10 100                             | 357                                | 14.3                               | 2.69                               | 572                                | 56.6                               | 654    | 88.7  | 0.872                | 35.3                 | 0.104                | 14.9 | 49.4 |
|             | 54          | 310.9            | 166.8            | 7.7           | 13.7        | 8.9                   | 265.7                    | 7.38                  | 52.7               | 8 200                              | 280                                | 14.0                               | 2.59                               | 471                                | 44.7                               | 540    | 70.2  | 0.864                | 42.2                 | 0.081                | 8.68 | 41.8 |
|             | 46          | 307.1            | 165.7            | 6.7           | 11.8        | 8.9                   | 265.7                    | 6.09                  | 34.5               | 11 700                             | 1 060                              | 13.1                               | 3.94                               | 753                                | 127                                | 845    | 195   | 0.89                 | 23.7                 | 0.234                | 34.5 | 68.4 |
| 305x165     | 40          | 303.8            | 165.1            | 6.1           | 10.2        | 8.9                   | 265.7                    | 7.02                  | 39.7               | 9 950                              | 897                                | 3.0                                | 3.90                               | 648                                | 108                                | 723    | 166   | 0.89                 | 27.2                 | 0.196                | 22.5 | 58.9 |
|             | 48          | 310.4            | 125.2            | 8.9           | 14.0        | 8.9                   | 264.6                    | 4.47                  | 29.7               | 9 500                              | 460                                | 12.5                               | 2.75                               | 612                                | 73.5                               | 706    | 116   | 0.874                | 31.1                 | 0.164                | 14.7 | 51.5 |
|             | 42          | 306.6            | 124.3            | 8.0           | 12.1        | 8.9                   | 264.6                    | 5.14                  | 33.1               | 8 140                              | 388                                | 12.4                               | 2.70                               | 531                                | 62.5                               | 610    | 98.2  | 0.872                | 26.5                 | 0.0842               | 21.0 | 53.2 |

h b t<sub>w</sub> t<sub>f</sub> r h<sub>w</sub> c/t<sub>w</sub> I<sub>y</sub> I<sub>z</sub> i<sub>y</sub> i<sub>z</sub> Z<sub>y</sub> Z<sub>z</sub> W<sub>pl,y</sub> W<sub>pl,z</sub> I<sub>w</sub> I<sub>t</sub> A ← EC3 notation

Table B1 Continued

| Serial size | Designation | Dimensions       |                  |               |                  |             | Properties            |                          |                       |                             |                             |                             |                             |                             |                             |      |  |                      |                      |                      |      |
|-------------|-------------|------------------|------------------|---------------|------------------|-------------|-----------------------|--------------------------|-----------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|------|--|----------------------|----------------------|----------------------|------|
|             |             | Depth of section | Width of section | Web thickness | Flange thickness | Root radius | Depth between fillets | Ratio for local buckling | Second moment of area |                             | Radius of gyration          |                             | Elastic modulus             |                             | Plastic modulus             |      | Buckling Torsional Warping Torsional Area of parameter index constant constant section |                      |                      |                      |      |
| (mm)        | (kg)        | D                | B                | t             | T                | r           | d                     | Flange b/T               | Web d/t               | Axis x-x (cm <sup>4</sup> ) | Axis y-y (cm <sup>4</sup> ) | Axis x-x (cm <sup>3</sup> ) | Axis y-y (cm <sup>3</sup> ) | Axis x-x (cm <sup>3</sup> ) | Axis y-y (cm <sup>3</sup> ) | u    | x  | H (dm <sup>6</sup> ) | J (cm <sup>4</sup> ) | A (cm <sup>2</sup> ) |      |
| 37          | 303.8       | 123.5            | 7.2              | 10.7          | 8.9              | 264.6       | 5.77                  | 36.7                     | 7.160                 | 337                         | 12.3                        | 2.67                        | 472                         | 54.6                        | 540                         | 85.7 | 0.871  | 29.6                 | 0.0724               | 14.9                 | 47.5 |
| 33          | 312.7       | 102.4            | 6.6              | 10.8          | 7.6              | 275.9       | 4.74                  | 41.8                     | 6.490                 | 193                         | 12.5                        | 2.15                        | 415                         | 37.8                        | 480                         | 59.8 | 0.866  | 31.7                 | 0.0441               | 12.1                 | 41.8 |
| 28          | 308.9       | 101.9            | 6.1              | 8.9           | 7.6              | 275.9       | 5.72                  | 45.2                     | 5.420                 | 157                         | 12.2                        | 2.08                        | 351                         | 30.8                        | 407                         | 48.9 | 0.858  | 37.0                 | 0.0353               | 7.63                 | 36.3 |
| 25          | 304.8       | 101.6            | 5.8              | 6.8           | 7.6              | 275.9       | 7.47                  | 47.6                     | 4.390                 | 120                         | 11.8                        | 1.96                        | 288                         | 23.6                        | 338                         | 38.0 | 0.844  | 43.8                 | 0.0266               | 4.65                 | 31.4 |
| 43          | 259.6       | 147.3            | 7.3              | 12.7          | 7.6              | 218.9       | 5.80                  | 30.0                     | 6.560                 | 677                         | 10.9                        | 3.51                        | 505                         | 92.0                        | 568                         | 141  | 0.889  | 21.1                 | 0.103                | 24.1                 | 55.1 |
| 37          | 256.0       | 146.4            | 6.4              | 10.9          | 7.6              | 218.9       | 6.72                  | 34.2                     | 5.560                 | 571                         | 10.8                        | 3.47                        | 434                         | 78.1                        | 485                         | 120  | 0.889  | 24.3                 | 0.0858               | 15.5                 | 47.5 |
| 31          | 251.5       | 146.1            | 6.1              | 8.6           | 7.6              | 218.9       | 8.49                  | 35.9                     | 4.440                 | 449                         | 10.5                        | 3.35                        | 353                         | 61.5                        | 396                         | 94.5 | 0.879  | 29.4                 | 0.0662               | 8.73                 | 40.0 |
| 28          | 260.4       | 102.1            | 6.4              | 10.0          | 7.6              | 225.1       | 5.10                  | 35.2                     | 4.010                 | 178                         | 10.5                        | 2.22                        | 308                         | 34.9                        | 353                         | 54.8 | 0.873  | 27.5                 | 0.0279               | 9.64                 | 36.2 |
| 25          | 257.0       | 101.9            | 6.1              | 8.4           | 7.6              | 225.1       | 6.07                  | 36.9                     | 3.410                 | 148                         | 10.3                        | 2.14                        | 265                         | 29.0                        | 306                         | 45.8 | 0.864  | 31.4                 | 0.0228               | 6.45                 | 32.2 |
| 22          | 254.0       | 101.6            | 5.8              | 6.8           | 7.6              | 225.1       | 7.47                  | 38.8                     | 2.870                 | 120                         | 10.00                       | 2.05                        | 226                         | 23.6                        | 262                         | 37.5 | 0.854  | 35.9                 | 0.0183               | 4.31                 | 28.4 |
| 30          | 206.8       | 133.8            | 6.3              | 9.6           | 7.6              | 172.3       | 6.97                  | 27.3                     | 2.890                 | 384                         | 8.72                        | 3.18                        | 279                         | 57.4                        | 313                         | 88.1 | 0.882  | 21.5                 | 0.0373               | 10.2                 | 38.0 |
| 25          | 203.2       | 133.4            | 5.8              | 7.8           | 7.6              | 172.3       | 8.55                  | 29.7                     | 2.360                 | 310                         | 8.54                        | 3.10                        | 232                         | 46.4                        | 260                         | 71.4 | 0.876  | 25.4                 | 0.0295               | 6.12                 | 32.3 |
| 23          | 203.2       | 101.6            | 5.2              | 9.3           | 7.6              | 169.4       | 5.46                  | 32.6                     | 2.090                 | 163                         | 8.49                        | 2.37                        | 206                         | 32.1                        | 232                         | 49.5 | 0.89   | 22.6                 | 0.0153               | 6.87                 | 29.0 |
| 178x102     | 19          | 177.8            | 101.6            | 4.7           | 7.9              | 7.6         | 146.8                 | 6.43                     | 31.2                  | 1360                        | 7.49                        | 2.39                        | 153                         | 27.2                        | 171                         | 41.9 | 0.889  | 22.6                 | 0.00908              | 4.37                 | 24.2 |
| 152x89      | 16          | 152.4            | 88.9             | 4.6           | 7.7              | 7.6         | 121.8                 | 5.77                     | 26.5                  | 838                         | 6.40                        | 2.10                        | 110                         | 20.3                        | 124                         | 31.4 | 0.889  | 19.5                 | 0.00473              | 3.61                 | 20.5 |
| 127x76      | 13          | 127.0            | 76.2             | 4.2           | 7.6              | 96.6        | 5.01                  | 23.0                     | 477                   | 56.2                        | 5.33                        | 1.83                        | 75.1                        | 14.7                        | 85                          | 22.7 | 0.893  | 16.2                 | 0.002                | 2.92                 | 16.8 |

h b t<sub>w</sub> t<sub>f</sub> r h<sub>w</sub> c/t<sub>w</sub> I<sub>y</sub> I<sub>z</sub> i<sub>y</sub> i<sub>z</sub> Z<sub>y</sub> Z<sub>z</sub> W<sub>pl,y</sub> W<sub>pl,z</sub> I<sub>w</sub> I<sub>t</sub> A

**Table B2** Dimensions and properties of steel universal columns (structural sections to BS 4: Part 1 and BS 4848: Part 4)

| Serial size | Designation | Mass per metre | Dimensions       |                  |               |                  |             |                       |                           |         |                       |                    | Properties         |                  |                    |                    |                    |                    |                    |                    |                    |                    |                    |
|-------------|-------------|----------------|------------------|------------------|---------------|------------------|-------------|-----------------------|---------------------------|---------|-----------------------|--------------------|--------------------|------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|             |             |                | Depth of section | Width of section | Web thickness | Flange thickness | Root radius | Depth between fillets | Ratios for local buckling |         | Second moment of area |                    | Radius of gyration |                  | Elastic modulus    |                    | Plastic modulus    |                    | Buckling parameter |                    | Torsional constant |                    | Area of section    |
| (mm)        |             | (kg)           | D                | B                | t             | T                | F           | d                     | Flange b/T                | Web d/t | A <sub>x-x</sub>      | A <sub>y-y</sub>   | A <sub>x-x</sub>   | A <sub>y-y</sub> | A <sub>x-x</sub>   | A <sub>y-y</sub>   | A <sub>x-x</sub>   | A <sub>y-y</sub>   | u                  | x                  | H                  | y                  | A                  |
|             |             |                | (mm)             | (mm)             | (mm)          | (mm)             | (mm)        | (mm)                  |                           |         | (cm <sup>2</sup> )    | (cm <sup>2</sup> ) | (cm)               | (cm)             | (cm <sup>2</sup> ) | (cm <sup>2</sup> ) | (cm <sup>3</sup> ) | (cm <sup>3</sup> ) |                    | (dm <sup>3</sup> ) | (cm <sup>4</sup> ) | (cm <sup>4</sup> ) | (cm <sup>2</sup> ) |
| 356x406     | 634         | 474.7          | 424.1            | 47.6             | 77.0          | 15.2             | 290.2       | 2.75                  | 6.10                      | 275 000 | 98 200                | 18.5               | 11.0               | 11 600           | 4 630              | 14 200             | 7 110              | 0.843              | 5.46               | 38.8               | 13 700             | 808                |                    |
|             | 551         | 455.7          | 418.5            | 42.0             | 67.5          | 15.2             | 290.2       | 3.10                  | 6.91                      | 227 000 | 82 700                | 18.0               | 10.9               | 9 960            | 3 950              | 12 100             | 6 060              | 0.841              | 6.05               | 31.1               | 9 240              | 702                |                    |
|             | 467         | 436.6          | 412.4            | 35.9             | 58.0          | 15.2             | 290.2       | 3.56                  | 8.08                      | 183 000 | 67 900                | 17.5               | 10.7               | 8 390            | 3 200              | 10 000             | 5 040              | 0.839              | 6.86               | 24.3               | 5 820              | 595                |                    |
|             | 393         | 419.1          | 407.0            | 30.6             | 49.2          | 15.2             | 290.2       | 4.14                  | 9.48                      | 147 000 | 55 400                | 17.1               | 10.5               | 7 000            | 2 720              | 8 230              | 4 160              | 0.837              | 7.86               | 19.0               | 3 550              | 501                |                    |
|             | 340         | 406.4          | 403.0            | 26.5             | 42.9          | 15.2             | 290.2       | 4.70                  | 11.0                      | 122 000 | 46 800                | 16.8               | 10.4               | 6 030            | 2 320              | 6 990              | 3 540              | 0.836              | 8.85               | 15.5               | 2 340              | 433                |                    |
|             | 287         | 393.7          | 399.0            | 22.6             | 36.5          | 15.2             | 290.2       | 5.47                  | 12.8                      | 100 000 | 38 700                | 16.5               | 10.3               | 5 080            | 1 940              | 5 820              | 2 950              | 0.835              | 10.2               | 12.3               | 1 440              | 366                |                    |
|             | 235         | 381.0          | 395.0            | 18.5             | 30.2          | 15.2             | 290.2       | 6.54                  | 15.7                      | 79 100  | 31 000                | 16.2               | 10.2               | 4 150            | 1 570              | 4 690              | 2 380              | 0.834              | 12.1               | 9.54               | 812                | 300                |                    |
|             | COLCORE     | 477            | 427.0            | 424.4            | 48.0          | 53.2             | 15.2        | 290.2                 | 3.99                      | 6.05    | 172 000               | 68 100             | 16.8               | 10.6             | 8 080              | 3 210              | 9 700              | 4 980              | 0.815              | 6.91               | 23.8               | 5 700              | 607                |
|             | 356x368     | 202            | 374.7            | 374.4            | 16.8          | 27.0             | 15.2        | 290.2                 | 6.93                      | 17.3    | 66 300                | 23 600             | 16.0               | 9.57             | 3 540              | 1 260              | 3 980              | 1 920              | 0.844              | 13.3               | 7.14               | 560                | 258                |
|             | 177         | 368.3          | 372.1            | 14.5             | 23.8          | 15.2             | 290.2       | 7.82                  | 20.0                      | 57 200  | 20 500                | 15.9               | 9.52               | 3 100            | 1 100              | 3 460              | 1 670              | 0.844              | 15.0               | 6.07               | 383                | 226                |                    |
| 305x305     | 153         | 362.0          | 370.2            | 12.6             | 20.7          | 15.2             | 290.2       | 8.94                  | 23.0                      | 48 500  | 17 500                | 15.8               | 9.46               | 2 680            | 944                | 2 960              | 1 430              | 0.844              | 17.0               | 5.09               | 251                | 195                |                    |
|             | 129         | 355.6          | 368.3            | 10.7             | 17.5          | 15.2             | 290.2       | 10.5                  | 27.1                      | 40 200  | 14 600                | 15.6               | 9.39               | 2 260            | 790                | 2 480              | 1 200              | 0.843              | 19.5               | 4.13               | 153                | 165                |                    |
|             | 283         | 365.3          | 321.8            | 26.9             | 44.1          | 15.2             | 246.6       | 3.65                  | 9.17                      | 78 800  | 24 500                | 14.8               | 8.25               | 4 310            | 1 530              | 5 100              | 2 340              | 0.855              | 7.65               | 6.33               | 2 030              | 360                |                    |
|             | 240         | 352.6          | 317.9            | 23.0             | 37.7          | 15.2             | 246.6       | 4.22                  | 10.7                      | 64 200  | 20 200                | 14.5               | 8.14               | 3 640            | 1 270              | 4 250              | 1 950              | 0.854              | 8.73               | 5.01               | 1 270              | 306                |                    |
|             | 198         | 339.9          | 314.1            | 19.2             | 31.4          | 15.2             | 246.6       | 5.00                  | 12.8                      | 50 800  | 16 200                | 14.2               | 8.02               | 2 990            | 1 030              | 3 440              | 1 580              | 0.854              | 10.2               | 3.86               | 734                | 252                |                    |
|             | 158         | 327.2          | 310.6            | 15.7             | 25.0          | 15.2             | 246.6       | 6.21                  | 15.7                      | 38 700  | 12 500                | 13.9               | 7.89               | 2 370            | 806                | 2 680              | 1 230              | 0.852              | 12.5               | 2.86               | 379                | 201                |                    |
|             | 137         | 320.5          | 308.7            | 13.8             | 21.7          | 15.2             | 246.6       | 7.11                  | 17.9                      | 32 800  | 10 700                | 13.7               | 7.82               | 2 050            | 691                | 2 300              | 1 050              | 0.851              | 14.1               | 2.38               | 250                | 175                |                    |
|             | 118         | 314.5          | 306.8            | 11.9             | 18.7          | 15.2             | 246.6       | 8.20                  | 20.7                      | 27 600  | 9 010                 | 13.6               | 7.75               | 1 760            | 587                | 1 950              | 892                | 0.851              | 16.2               | 1.97               | 160                | 150                |                    |
|             | 254x254     | 97             | 307.8            | 304.8            | 9.9           | 15.4             | 15.2        | 246.6                 | 9.90                      | 24.9    | 22 200                | 7 270              | 13.4               | 7.68             | 1 440              | 477                | 1 590              | 723                | 0.85               | 19.3               | 1.55               | 91.1               | 123                |
|             | 132         | 276.4          | 261.0            | 15.6             | 25.3          | 12.7             | 200.3       | 5.16                  | 12.8                      | 22 600  | 7 520                 | 11.6               | 6.67               | 1 630            | 576                | 1 870              | 879                | 0.85               | 10.3               | 1.18               | 322                | 169                |                    |
| 203x203     | 107         | 266.7          | 258.3            | 13.0             | 20.5          | 12.7             | 200.3       | 6.30                  | 15.4                      | 17 500  | 5 900                 | 11.3               | 6.57               | 1 310            | 457                | 1 490              | 695                | 0.848              | 12.4               | 0.894              | 173                | 137                |                    |
|             | 89          | 260.4          | 255.9            | 10.5             | 17.3          | 12.7             | 200.3       | 7.40                  | 19.1                      | 14 300  | 4 850                 | 11.2               | 6.52               | 1 100            | 379                | 1 230              | 575                | 0.849              | 14.4               | 0.716              | 104                | 114                |                    |
|             | 73          | 254.0          | 254.0            | 8.6              | 14.2          | 12.7             | 200.3       | 8.94                  | 23.3                      | 11 400  | 3 870                 | 11.1               | 6.46               | 894              | 305                | 989                | 462                | 0.849              | 17.3               | 0.557              | 57.3               | 92.9               |                    |
|             | 86          | 222.3          | 208.8            | 13.0             | 20.5          | 10.2             | 160.9       | 5.09                  | 12.4                      | 9 460   | 3 120                 | 9.27               | 5.32               | 851              | 299                | 979                | 456                | 0.85               | 10.2               | 0.317              | 138                | 110                |                    |
|             | 71          | 215.9          | 206.2            | 10.3             | 17.3          | 10.2             | 160.9       | 5.96                  | 15.6                      | 7 650   | 2 540                 | 9.16               | 5.28               | 708              | 246                | 802                | 374                | 0.852              | 11.9               | 0.25               | 81.5               | 91.1               |                    |
|             | 60          | 209.6          | 205.2            | 9.3              | 14.2          | 10.2             | 160.9       | 7.23                  | 17.3                      | 6 090   | 2 040                 | 8.96               | 5.19               | 581              | 199                | 652                | 303                | 0.847              | 14.1               | 0.195              | 46.6               | 75.8               |                    |
|             | 52          | 206.2          | 203.9            | 8.0              | 12.5          | 10.2             | 160.9       | 8.16                  | 20.1                      | 5 260   | 1 770                 | 8.90               | 5.16               | 510              | 174                | 568                | 264                | 0.848              | 15.8               | 0.166              | 32.0               | 66.4               |                    |
|             | 46          | 203.2          | 203.2            | 7.3              | 11.0          | 10.2             | 160.9       | 9.24                  | 22.0                      | 4 560   | 1 540                 | 8.81               | 5.11               | 449              | 151                | 497                | 230                | 0.846              | 17.7               | 0.142              | 22.2               | 58.8               |                    |
|             | 152x152     | 37             | 161.8            | 154.4            | 8.1           | 11.5             | 7.6         | 123.5                 | 6.71                      | 15.2    | 2 220                 | 709                | 6.84               | 3.87             | 274                | 91.8               | 310                | 140                | 0.848              | 13.3               | 0.04               | 19.5               | 47.4               |
|             | 30          | 157.5          | 152.9            | 6.6              | 9.4           | 7.6              | 123.5       | 8.13                  | 18.7                      | 1 740   | 558                   | 6.75               | 3.82               | 221              | 73.1               | 247                | 111                | 0.848              | 16.0               | 0.0306             | 10.5               | 38.2               |                    |
| 23          | 152.4       | 152.4          | 6.1              | 6.8              | 7.6           | 123.5            | 11.2        | 20.2                  | 1 260                     | 403     | 6.51                  | 3.68               | 166                | 52.9             | 184                | 80.9               | 0.837              | 20.4               | 0.0214             | 4.87               | 29.8               |                    |                    |

h b t<sub>w</sub> t<sub>f</sub> r h<sub>w</sub> c/t<sub>w</sub> I<sub>y</sub> I<sub>z</sub> i<sub>y</sub> i<sub>z</sub> Z<sub>y</sub> Z<sub>z</sub> W<sub>pl,y</sub> W<sub>pl,z</sub> I<sub>w</sub> I<sub>t</sub> A

## APPENDIX B:

### DESIGN DATA

#### (a) Columns in simple construction

$$\frac{N_{Ed}}{N_{b,z,Rd}} + \frac{M_{y,Ed}}{M_{b,Rd}} + 1.5 \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1.0$$

where

$M_{b,Rd} = \chi_{LT} W_y f_y / \gamma_{M1}$  (from clause 6.3.2.1, EC3 Part 1.1)

$M_{z,Rd} = W_{pl,z} f_y / \gamma_{M1}$

$N_{b,z,Rd} = \chi_z A f_y / \gamma_{M1}$

#### (b) Classification of cross sections subject to combined axial load and bending

$$\alpha = \frac{1}{2} \left( 1 + \frac{N_{Ed}}{t_w d f_y} \right) \leq 1.0$$

#### (c) Elastic critical moment

The elastic critical moment for lateral torsional buckling,  $M_{cr}$ , for a beam may be taken as:

$$M_{cr} = C_1 \frac{\pi}{L_{cr}} (E I_z G I_t)^{0.5} \left( 1 + \frac{\pi^2 E I_w}{L_{cr}^2 G I_t} \right)^{0.5}$$

|       |          |   |
|-------|----------|---|
| where | $C_1$    | Bending moment shape factor (see Table 1, page 9) |
|       | $E$      | Young's modulus                                   |
|       | $G$      | Shear modulus                                     |
|       | $I_t$    | Torsion constant for the section                  |
|       | $I_w$    | Warping constant for the section                  |
|       | $L_{cr}$ | Critical buckling length                          |
|       | $I_z$    | Moment of inertia about z-z axis                  |

#### (d) Deflection

Maximum deflection,  $\delta$ , of a simply supported beam supporting two point-loads  $W/2$  at the third points is obtained from (Arya, Design of Structural Elements, 3<sup>rd</sup> Ed, 2009, p22)

$$\delta = \frac{23WL^3}{1296EI}$$

where  $L$  is the span length,  $E$  the Young's modulus and  $I$  the second moment of area



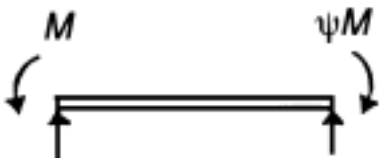


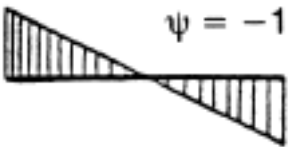
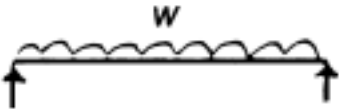
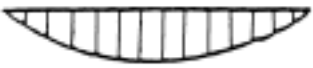
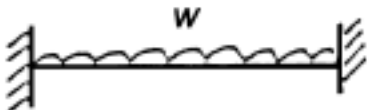



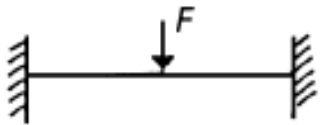

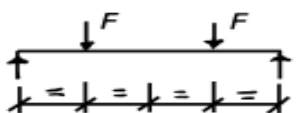
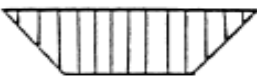
| Loading and support conditions  | Bending moment diagram  | $\psi$ | $C_1$ |
|---|---|--------|-------|
|    | (a) $\psi = +1$<br> | +1     | 1.00  |
|   | (b) $\psi = 0$<br>  | 0      | 1.88  |
|   | (c) $\psi = -1$<br> | -1     | 2.75  |
|    | (d)<br>             | -      | 1.132 |
|   | (e)<br>           | -      | 1.285 |
|  | (f)<br>           | -      | 1.365 |
|  | (g)<br>           | -      | 1.565 |
|  | (h)<br>           | -      | 1.046 |

Table 1