**Novel hybrid machine learning models for failure mode identification and shear strength prediction of rectangular hollow RC columns subjected to compressive and lateral loads**

Viet-Linh Tran1, Duy-Duan Nguyen1, Van-Tien Phan1, Trong-Ha Nguyen1, Tae-Hyung Lee2\*

1 Department of Civil Engineering, Vinh University, Vinh 461010, Vietnam

2 Department of Civil and Environmental Engineering, Konkuk University, Seoul 05029, Korea

\*Corresponding author

Email addresses: vietlinh.dhv@gmail.com (Viet-Linh Tran); duan468@gmail.com (Duy-Duan Nguyen); vantienkxd@vinhuni.edu.vn (Van-Tien Phan); trongha.kxd@gmail.com (Trong-Ha Nguyen); thlee@konkuk.ac.kr (Tae-Hyung Lee)

**1. Results of shear strength prediction**

**A picture containing screenshot, colorfulness, purple, magenta

Description automatically generated**

**A picture containing text, screenshot, businesscard, font

Description automatically generated**

**Fig. S-1.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 50.

A picture containing screenshot, colorfulness, purple, magenta

Description automatically generated

A picture containing text, screenshot, businesscard, font

Description automatically generated

**Fig. S-2.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 100.

A picture containing screenshot, colorfulness, purple, magenta

Description automatically generated

A picture containing text, screenshot, businesscard, font

Description automatically generated

**Fig. S-3.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 150.

A picture containing screenshot, colorfulness, purple, magenta

Description automatically generated

A picture containing text, screenshot, businesscard, font

Description automatically generated

**Fig. S-4.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 200.

A picture containing screenshot, colorfulness, purple, magenta

Description automatically generated

A picture containing text, screenshot, businesscard, font

Description automatically generated

**Fig. S-5.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 250.

A picture containing screenshot, colorfulness, purple, magenta

Description automatically generated

A picture containing text, screenshot, businesscard, font

Description automatically generated

**Fig. S-6.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 300.

**Table S-1** Performance of MFO-DT models on the training set

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Pop** | **Tr.atio** | **R2** | **Score** | **A10** | **Score** | **RMSE** | **Score** | **MAE** | **Score** | **Total** |
| 50 | 0.55 | 0.998 | 16 | 0.773 | 12 | 31.266 | 16 | 18.25 | 16 | 60 |
|  | 0.60 | 0.999 | 23 | 0.917 | 24 | 18.809 | 29 | 10.382 | 24 | 100 |
|  | 0.65 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.70 | 0.972 | 9 | 0.679 | 7 | 95.407 | 9 | 41.804 | 9 | 34 |
|  | 0.75 | 0.999 | 23 | 0.933 | 29 | 19.456 | 24 | 9.833 | 29 | 105 |
|  | 0.80 | 0.992 | 11 | 0.854 | 20 | 55.347 | 11 | 22.437 | 12 | 54 |
|  | 0.85 | 1 | 37 | 1 | 38 | 0.328 | 38 | 0.078 | 38 | 151 |
|  | 0.90 | 0.916 | 1 | 0.491 | 2 | 174.199 | 2 | 79.261 | 2 | 7 |
| 100 | 0.55 | 0.998 | 16 | 0.773 | 12 | 31.266 | 16 | 18.25 | 16 | 60 |
|  | 0.60 | 0.999 | 23 | 0.917 | 24 | 18.809 | 29 | 10.382 | 24 | 100 |
|  | 0.65 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.70 | 0.99 | 10 | 0.726 | 10 | 58.189 | 10 | 26.05 | 10 | 40 |
|  | 0.75 | 0.999 | 23 | 0.933 | 29 | 19.456 | 24 | 9.833 | 29 | 105 |
|  | 0.80 | 0.992 | 11 | 0.854 | 20 | 55.347 | 11 | 22.437 | 12 | 54 |
|  | 0.85 | 0.992 | 11 | 0.824 | 19 | 54.17 | 15 | 22.985 | 11 | 56 |
|  | 0.90 | 0.916 | 1 | 0.491 | 2 | 174.199 | 2 | 79.261 | 2 | 7 |
| 150 | 0.55 | 0.998 | 16 | 0.773 | 12 | 31.266 | 16 | 18.25 | 16 | 60 |
|  | 0.60 | 0.999 | 23 | 0.917 | 24 | 18.809 | 29 | 10.382 | 24 | 100 |
|  | 0.65 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.70 | 0.999 | 23 | 0.952 | 34 | 15.854 | 34 | 8.297 | 34 | 125 |
|  | 0.75 | 0.999 | 23 | 0.933 | 29 | 19.456 | 24 | 9.833 | 29 | 105 |
|  | 0.80 | 0.992 | 11 | 0.854 | 20 | 55.347 | 11 | 22.437 | 12 | 54 |
|  | 0.85 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.90 | 0.916 | 1 | 0.491 | 2 | 174.199 | 2 | 79.261 | 2 | 7 |
| 200 | 0.55 | 0.998 | 16 | 0.773 | 12 | 31.266 | 16 | 18.25 | 16 | 60 |
|  | 0.60 | 0.971 | 8 | 0.639 | 5 | 103.655 | 8 | 48.362 | 8 | 29 |
|  | 0.65 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.70 | 1 | 37 | 0.976 | 37 | 5.5 | 37 | 1.317 | 37 | 148 |
|  | 0.75 | 0.998 | 16 | 0.789 | 18 | 24.412 | 22 | 16.17 | 22 | 78 |
|  | 0.80 | 0.992 | 11 | 0.854 | 20 | 55.347 | 11 | 22.437 | 12 | 54 |
|  | 0.85 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.90 | 0.916 | 1 | 0.481 | 1 | 174.226 | 1 | 79.285 | 1 | 4 |
| 250 | 0.55 | 0.998 | 16 | 0.773 | 12 | 31.266 | 16 | 18.25 | 16 | 60 |
|  | 0.60 | 0.999 | 23 | 0.917 | 24 | 18.809 | 29 | 10.382 | 24 | 100 |
|  | 0.65 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.70 | 0.999 | 23 | 0.952 | 34 | 15.854 | 34 | 8.297 | 34 | 125 |
|  | 0.75 | 0.999 | 23 | 0.933 | 29 | 19.456 | 24 | 9.833 | 29 | 105 |
|  | 0.80 | 0.999 | 23 | 0.76 | 11 | 20.584 | 23 | 11.899 | 23 | 80 |
|  | 0.85 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | **0.90** | 0.943 | 5 | 0.704 | 8 | 144.484 | 6 | 58.652 | 6 | 25 |
| 300 | 0.55 | 0.998 | 16 | 0.773 | 12 | 31.266 | 16 | 18.25 | 16 | 60 |
|  | 0.60 | 0.999 | 23 | 0.917 | 24 | 18.809 | 29 | 10.382 | 24 | 100 |
|  | 0.65 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.70 | 0.999 | 23 | 0.952 | 34 | 15.854 | 34 | 8.297 | 34 | 125 |
|  | 0.75 | 0.999 | 23 | 0.933 | 29 | 19.456 | 24 | 9.833 | 29 | 105 |
|  | 0.80 | 0.944 | 7 | 0.677 | 6 | 150.075 | 5 | 59.688 | 5 | 23 |
|  | 0.85 | 1 | 37 | 1 | 38 | 0 | 39 | 0 | 39 | 153 |
|  | 0.90 | 0.943 | 5 | 0.704 | 8 | 144.484 | 6 | 58.652 | 6 | 25 |

**Table S-2** Performance of MFO-DT models on the test set

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Pop** | **Tr.atio** | **R2** | **Score** | **A10** | **Score** | **RMSE** | **Score** | **MAE** | **Score** | **Total** |
| 50 | 0.55 | 0.37 | 8 | 0.236 | 3 | 544.278 | 20 | 228.452 | 16 | 47 |
|  | 0.60 | 0.447 | 23 | 0.327 | 20 | 534.586 | 26 | 197.613 | 26 | 95 |
|  | 0.65 | 0.376 | 14 | 0.372 | 38 | 596.396 | 10 | 238.758 | 3 | 65 |
|  | 0.70 | 0.439 | 22 | 0.27 | 14 | 598.855 | 9 | 244.054 | 2 | 47 |
|  | 0.75 | 0.363 | 2 | 0.355 | 28 | 628.058 | 2 | 231.576 | 10 | 42 |
|  | **0.80** | **0.922** | **41** | **0.36** | **33** | **203.606** | **45** | **97.192** | **45** | **164** |
|  | 0.85 | 0.916 | 33 | 0.211 | 2 | 238.449 | 37 | 124.433 | 37 | 109 |
|  | 0.90 | 0.917 | 34 | 0.385 | 44 | 272.975 | 33 | 141.455 | 33 | 144 |
| 100 | 0.55 | 0.37 | 8 | 0.236 | 3 | 544.278 | 20 | 228.452 | 16 | 47 |
|  | 0.60 | 0.447 | 23 | 0.327 | 20 | 534.586 | 26 | 197.613 | 26 | 95 |
|  | 0.65 | 0.376 | 14 | 0.372 | 38 | 596.396 | 10 | 238.758 | 3 | 65 |
|  | 0.70 | 0.362 | 1 | 0.243 | 9 | 638.573 | 1 | 279.875 | 1 | 12 |
|  | 0.75 | 0.363 | 2 | 0.355 | 28 | 628.058 | 2 | 231.576 | 10 | 42 |
|  | 0.80 | 0.922 | 41 | 0.36 | 33 | 203.606 | 45 | 97.192 | 45 | 164 |
|  | 0.85 | 0.921 | 40 | 0.316 | 17 | 230.859 | 38 | 112.311 | 42 | 137 |
|  | 0.90 | 0.917 | 34 | 0.385 | 44 | 272.975 | 33 | 141.455 | 33 | 144 |
| 150 | 0.55 | 0.37 | 8 | 0.236 | 3 | 544.278 | 20 | 228.452 | 16 | 47 |
|  | 0.60 | 0.447 | 23 | 0.327 | 20 | 534.586 | 26 | 197.613 | 26 | 95 |
|  | 0.65 | 0.376 | 14 | 0.372 | 38 | 596.396 | 10 | 238.758 | 3 | 65 |
|  | 0.70 | 0.459 | 28 | 0.351 | 25 | 588.3 | 16 | 220.635 | 22 | 91 |
|  | 0.75 | 0.363 | 2 | 0.355 | 28 | 628.058 | 2 | 231.576 | 10 | 42 |
|  | 0.80 | 0.922 | 41 | 0.36 | 33 | 203.606 | 45 | 97.192 | 45 | 164 |
|  | 0.85 | 0.924 | 45 | 0.263 | 10 | 227.041 | 39 | 115.354 | 38 | 132 |
|  | 0.90 | 0.917 | 34 | 0.385 | 44 | 272.975 | 33 | 141.455 | 33 | 144 |
| 200 | 0.55 | 0.37 | 8 | 0.236 | 3 | 544.278 | 20 | 228.452 | 16 | 47 |
|  | 0.60 | 0.419 | 20 | 0.122 | 1 | 547.7 | 19 | 219.581 | 25 | 65 |
|  | 0.65 | 0.376 | 14 | 0.372 | 38 | 596.396 | 10 | 238.758 | 3 | 65 |
|  | 0.70 | 0.429 | 21 | 0.324 | 19 | 604.28 | 8 | 236.088 | 9 | 57 |
|  | 0.75 | 0.363 | 2 | 0.387 | 48 | 627.938 | 7 | 230.384 | 15 | 72 |
|  | 0.80 | 0.922 | 41 | 0.36 | 33 | 203.606 | 45 | 97.192 | 45 | 164 |
|  | 0.85 | 0.924 | 45 | 0.263 | 10 | 227.041 | 39 | 115.354 | 38 | 132 |
|  | 0.90 | 0.917 | 34 | 0.385 | 44 | 272.811 | 36 | 140.061 | 36 | 150 |
| 250 | 0.55 | 0.37 | 8 | 0.236 | 3 | 544.278 | 20 | 228.452 | 16 | 47 |
|  | 0.60 | 0.447 | 23 | 0.327 | 20 | 534.586 | 26 | 197.613 | 26 | 95 |
|  | 0.65 | 0.376 | 14 | 0.372 | 38 | 596.396 | 10 | 238.758 | 3 | 65 |
|  | 0.70 | 0.459 | 28 | 0.351 | 25 | 588.3 | 16 | 220.635 | 22 | 91 |
|  | 0.75 | 0.363 | 2 | 0.355 | 28 | 628.058 | 2 | 231.576 | 10 | 42 |
|  | 0.80 | 0.919 | 39 | 0.32 | 18 | 207.469 | 44 | 104.804 | 43 | 144 |
|  | 0.85 | 0.924 | 45 | 0.263 | 10 | 227.041 | 39 | 115.354 | 38 | 132 |
|  | 0.90 | 0.912 | 31 | 0.308 | 15 | 280.825 | 31 | 145.341 | 31 | 108 |
| 300 | 0.55 | 0.37 | 8 | 0.236 | 3 | 544.278 | 20 | 228.452 | 16 | 47 |
|  | 0.60 | 0.447 | 23 | 0.327 | 20 | 534.586 | 26 | 197.613 | 26 | 95 |
|  | 0.65 | 0.376 | 14 | 0.372 | 38 | 596.396 | 10 | 238.758 | 3 | 65 |
|  | 0.70 | 0.459 | 28 | 0.351 | 25 | 588.3 | 16 | 220.635 | 22 | 91 |
|  | 0.75 | 0.363 | 2 | 0.355 | 28 | 628.058 | 2 | 231.576 | 10 | 42 |
|  | 0.80 | 0.918 | 38 | 0.36 | 33 | 209.044 | 43 | 104.102 | 44 | 158 |
|  | 0.85 | 0.924 | 45 | 0.263 | 10 | 227.041 | 39 | 115.354 | 38 | 132 |
|  | 0.90 | 0.912 | 31 | 0.308 | 15 | 280.825 | 31 | 145.341 | 31 | 108 |

**2. Results of failure modes identification**

A picture containing text, screenshot, font, graphic design

Description automatically generated

A picture containing screenshot, text, colorfulness, graphics

Description automatically generated

**Fig. S-7.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 50.

A picture containing screenshot, graphics, colorfulness, graphic design

Description automatically generated

A picture containing screenshot, graphics, colorfulness, graphic design

Description automatically generated

**Fig. S-8.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 100.

A picture containing text, screenshot, font, graphic design

Description automatically generated

A picture containing screenshot, text, graphics, graphic design

Description automatically generated

**Fig. S-9.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 150.

A picture containing text, screenshot, graphic design, font

Description automatically generated

A picture containing screenshot, text, graphics, graphic design

Description automatically generated

**Fig. S-10.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 200.

A picture containing screenshot, text, graphic design, graphics

Description automatically generated

A picture containing screenshot, graphics, graphic design, colorfulness

Description automatically generated

**Fig. S-11.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 250.

A picture containing text, screenshot, font, graphic design

Description automatically generated

A picture containing text, screenshot, graphics, graphic design

Description automatically generated

**Fig. S-12.** Effect of training-test ratios on the MFO-DT model’s performance with population size of 300.

**Table S-3** Performance of MFO-DT models on the training set

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Pop** | **Tr.atio** | **Acc** | **Score** | **Pre** | **Score** | **Re** | **Score** | **f1** | **Score** | **Total** |
| 50 | 0.55 | 0.69 | 21 | 0.691 | 18 | 0.69 | 21 | 0.689 | 21 | 81 |
|  | 0.60 | 0.642 | 9 | 0.66 | 13 | 0.642 | 9 | 0.648 | 14 | 45 |
|  | 0.65 | 0.72 | 26 | 0.724 | 25 | 0.72 | 26 | 0.714 | 22 | 99 |
|  | 0.70 | 0.641 | 7 | 0.683 | 17 | 0.641 | 7 | 0.624 | 5 | 36 |
|  | 0.75 | 0.723 | 28 | 0.729 | 27 | 0.723 | 28 | 0.723 | 29 | 112 |
|  | 0.80 | 0.719 | 22 | 0.716 | 22 | 0.719 | 22 | 0.717 | 25 | 91 |
|  | 0.85 | 0.645 | 13 | 0.649 | 8 | 0.645 | 13 | 0.625 | 8 | 42 |
|  | 0.90 | 0.817 | 42 | 0.823 | 42 | 0.817 | 42 | 0.816 | 42 | 168 |
| 100 | 0.55 | 0.93 | 47 | 0.937 | 47 | 0.93 | 47 | 0.93 | 47 | 188 |
|  | 0.60 | 0.651 | 17 | 0.655 | 12 | 0.651 | 17 | 0.649 | 17 | 63 |
|  | 0.65 | 0.864 | 46 | 0.865 | 46 | 0.864 | 46 | 0.863 | 46 | 184 |
|  | 0.70 | 0.641 | 7 | 0.704 | 20 | 0.641 | 7 | 0.625 | 7 | 41 |
|  | 0.75 | 0.766 | 39 | 0.77 | 39 | 0.766 | 39 | 0.765 | 39 | 156 |
|  | 0.80 | 0.719 | 22 | 0.716 | 22 | 0.719 | 22 | 0.717 | 25 | 91 |
|  | 0.85 | 0.606 | 3 | 0.621 | 2 | 0.606 | 3 | 0.611 | 3 | 11 |
|  | 0.90 | 0.817 | 42 | 0.823 | 42 | 0.817 | 42 | 0.816 | 42 | 168 |
| 150 | 0.55 | 0.72 | 25 | 0.745 | 36 | 0.72 | 25 | 0.715 | 24 | 110 |
|  | 0.60 | 0.642 | 9 | 0.66 | 13 | 0.642 | 9 | 0.648 | 14 | 45 |
|  | 0.65 | 0.627 | 5 | 0.652 | 11 | 0.627 | 5 | 0.634 | 13 | 34 |
|  | 0.70 | 0.602 | 2 | 0.622 | 3 | 0.602 | 2 | 0.608 | 2 | 9 |
|  | 0.75 | 0.73 | 31 | 0.743 | 32 | 0.73 | 31 | 0.73 | 32 | 126 |
|  | 0.80 | 0.842 | 44 | 0.842 | 44 | 0.842 | 44 | 0.841 | 44 | 176 |
|  | 0.85 | 0.645 | 13 | 0.649 | 8 | 0.645 | 13 | 0.625 | 8 | 42 |
|  | 0.90 | 0.683 | 20 | 0.693 | 19 | 0.683 | 20 | 0.668 | 19 | 78 |
| 200 | 0.55 | 0.52 | 1 | 0.402 | 1 | 0.52 | 1 | 0.43 | 1 | 4 |
|  | 0.60 | 0.734 | 35 | 0.732 | 29 | 0.734 | 35 | 0.73 | 35 | 134 |
|  | 0.65 | 0.729 | 30 | 0.737 | 30 | 0.729 | 30 | 0.722 | 28 | 118 |
|  | 0.70 | 0.812 | 40 | 0.816 | 40 | 0.812 | 40 | 0.813 | 40 | 160 |
|  | 0.75 | 0.73 | 31 | 0.743 | 32 | 0.73 | 31 | 0.73 | 32 | 126 |
|  | 0.80 | 0.644 | 12 | 0.638 | 4 | 0.644 | 12 | 0.628 | 11 | 39 |
|  | 0.85 | 0.645 | 13 | 0.643 | 6 | 0.645 | 13 | 0.628 | 12 | 44 |
|  | 0.90 | 0.738 | 37 | 0.751 | 37 | 0.738 | 37 | 0.735 | 37 | 148 |
| 250 | 0.55 | 0.85 | 45 | 0.86 | 45 | 0.85 | 45 | 0.849 | 45 | 180 |
|  | 0.60 | 0.642 | 9 | 0.66 | 13 | 0.642 | 9 | 0.648 | 14 | 45 |
|  | 0.65 | 0.72 | 26 | 0.724 | 25 | 0.72 | 26 | 0.714 | 22 | 99 |
|  | **0.70** | **0.812** | **40** | **0.816** | **40** | **0.812** | **40** | **0.813** | **40** | **160** |
|  | 0.75 | 0.723 | 28 | 0.729 | 27 | 0.723 | 28 | 0.723 | 29 | 112 |
|  | 0.80 | 0.616 | 4 | 0.64 | 5 | 0.616 | 4 | 0.624 | 6 | 19 |
|  | 0.85 | 0.942 | 48 | 0.946 | 48 | 0.942 | 48 | 0.942 | 48 | 192 |
|  | 0.90 | 0.64 | 6 | 0.643 | 7 | 0.64 | 6 | 0.62 | 4 | 23 |
| 300 | 0.55 | 0.68 | 19 | 0.682 | 16 | 0.68 | 19 | 0.68 | 20 | 74 |
|  | 0.60 | 0.743 | 38 | 0.763 | 38 | 0.743 | 38 | 0.738 | 38 | 152 |
|  | 0.65 | 0.669 | 18 | 0.708 | 21 | 0.669 | 18 | 0.657 | 18 | 75 |
|  | 0.70 | 0.734 | 36 | 0.738 | 31 | 0.734 | 36 | 0.733 | 36 | 139 |
|  | 0.75 | 0.73 | 31 | 0.743 | 32 | 0.73 | 31 | 0.73 | 32 | 126 |
|  | 0.80 | 0.719 | 22 | 0.716 | 22 | 0.719 | 22 | 0.717 | 25 | 91 |
|  | 0.85 | 0.645 | 13 | 0.649 | 8 | 0.645 | 13 | 0.625 | 8 | 42 |
|  | 0.90 | 0.732 | 34 | 0.743 | 35 | 0.732 | 34 | 0.727 | 31 | 134 |

**Table S-4** Performance of MFO-DT models on the test set

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Pop** | **Tr.atio** | **Acc** | **Score** | **Pre** | **Score** | **Re** | **Score** | **f1** | **Score** | **Total** |
| 50 | 0.55 | 0.651 | 29 | 0.674 | 26 | 0.651 | 29 | 0.655 | 30 | 114 |
|  | 0.60 | 0.541 | 4 | 0.551 | 5 | 0.541 | 4 | 0.543 | 9 | 22 |
|  | 0.65 | 0.615 | 23 | 0.601 | 12 | 0.615 | 23 | 0.602 | 20 | 78 |
|  | 0.70 | 0.618 | 26 | 0.739 | 35 | 0.618 | 26 | 0.602 | 18 | 105 |
|  | 0.75 | 0.609 | 18 | 0.645 | 19 | 0.609 | 18 | 0.607 | 23 | 78 |
|  | 0.80 | 0.73 | 35 | 0.735 | 31 | 0.73 | 35 | 0.73 | 35 | 136 |
|  | 0.85 | 0.571 | 12 | 0.627 | 16 | 0.571 | 12 | 0.538 | 6 | 46 |
|  | **0.90** | 0.789 | 41 | 0.821 | 42 | 0.789 | 41 | 0.792 | 41 | 165 |
| 100 | 0.55 | 0.819 | 44 | 0.833 | 45 | 0.819 | 44 | 0.819 | 45 | 178 |
|  | 0.60 | 0.514 | 1 | 0.513 | 2 | 0.514 | 1 | 0.512 | 4 | 8 |
|  | 0.65 | 0.831 | 46 | 0.879 | 48 | 0.831 | 46 | 0.837 | 48 | 188 |
|  | 0.70 | 0.618 | 26 | 0.739 | 35 | 0.618 | 26 | 0.602 | 18 | 105 |
|  | 0.75 | 0.652 | 30 | 0.669 | 25 | 0.652 | 30 | 0.647 | 29 | 114 |
|  | 0.80 | 0.73 | 35 | 0.735 | 31 | 0.73 | 35 | 0.73 | 35 | 136 |
|  | 0.85 | 0.571 | 12 | 0.577 | 10 | 0.571 | 12 | 0.573 | 16 | 50 |
|  | 0.90 | 0.789 | 41 | 0.821 | 42 | 0.789 | 41 | 0.792 | 41 | 165 |
| 150 | 0.55 | 0.723 | 34 | 0.736 | 34 | 0.723 | 34 | 0.709 | 33 | 135 |
|  | 0.60 | 0.541 | 4 | 0.551 | 5 | 0.541 | 4 | 0.543 | 9 | 22 |
|  | 0.65 | 0.554 | 9 | 0.555 | 8 | 0.554 | 9 | 0.55 | 15 | 41 |
|  | 0.70 | 0.6 | 17 | 0.599 | 11 | 0.6 | 17 | 0.597 | 17 | 62 |
|  | 0.75 | 0.609 | 18 | 0.645 | 19 | 0.609 | 18 | 0.607 | 23 | 78 |
|  | 0.80 | 0.811 | 43 | 0.814 | 41 | 0.811 | 43 | 0.812 | 43 | 170 |
|  | 0.85 | 0.571 | 12 | 0.627 | 16 | 0.571 | 12 | 0.538 | 6 | 46 |
|  | 0.90 | 0.526 | 2 | 0.514 | 3 | 0.526 | 2 | 0.47 | 2 | 9 |
| 200 | 0.55 | 0.542 | 8 | 0.361 | 1 | 0.542 | 8 | 0.43 | 1 | 18 |
|  | 0.60 | 0.703 | 32 | 0.711 | 29 | 0.703 | 32 | 0.705 | 32 | 125 |
|  | 0.65 | 0.615 | 23 | 0.601 | 12 | 0.615 | 23 | 0.602 | 20 | 78 |
|  | 0.70 | 0.836 | 47 | 0.852 | 46 | 0.836 | 47 | 0.836 | 46 | 186 |
|  | 0.75 | 0.609 | 18 | 0.645 | 19 | 0.609 | 18 | 0.607 | 23 | 78 |
|  | 0.80 | 0.568 | 10 | 0.622 | 15 | 0.568 | 10 | 0.547 | 13 | 48 |
|  | 0.85 | 0.536 | 3 | 0.557 | 9 | 0.536 | 3 | 0.51 | 3 | 18 |
|  | 0.90 | 0.737 | 38 | 0.74 | 38 | 0.737 | 38 | 0.735 | 38 | 152 |
| 250 | 0.55 | 0.771 | 40 | 0.786 | 40 | 0.771 | 40 | 0.773 | 40 | 160 |
|  | 0.60 | 0.541 | 4 | 0.551 | 5 | 0.541 | 4 | 0.543 | 9 | 22 |
|  | 0.65 | 0.615 | 23 | 0.601 | 12 | 0.615 | 23 | 0.602 | 20 | 78 |
|  | **0.70** | **0.836** | **47** | **0.852** | **46** | **0.836** | **47** | **0.836** | **46** | **186** |
|  | 0.75 | 0.609 | 18 | 0.645 | 19 | 0.609 | 18 | 0.607 | 23 | 78 |
|  | 0.80 | 0.541 | 4 | 0.537 | 4 | 0.541 | 4 | 0.537 | 5 | 17 |
|  | 0.85 | 0.821 | 45 | 0.83 | 44 | 0.821 | 45 | 0.815 | 44 | 178 |
|  | 0.90 | 0.579 | 16 | 0.7 | 27 | 0.579 | 16 | 0.55 | 14 | 73 |
| 300 | 0.55 | 0.627 | 28 | 0.657 | 24 | 0.627 | 28 | 0.63 | 28 | 108 |
|  | 0.60 | 0.689 | 31 | 0.704 | 28 | 0.689 | 31 | 0.672 | 31 | 121 |
|  | 0.65 | 0.569 | 11 | 0.73 | 30 | 0.569 | 11 | 0.546 | 12 | 64 |
|  | 0.70 | 0.709 | 33 | 0.739 | 37 | 0.709 | 33 | 0.709 | 34 | 137 |
|  | 0.75 | 0.609 | 18 | 0.645 | 19 | 0.609 | 18 | 0.607 | 23 | 78 |
|  | 0.80 | 0.73 | 35 | 0.735 | 31 | 0.73 | 35 | 0.73 | 35 | 136 |
|  | 0.85 | 0.571 | 12 | 0.627 | 16 | 0.571 | 12 | 0.538 | 6 | 46 |
|  | 0.90 | 0.737 | 38 | 0.74 | 38 | 0.737 | 38 | 0.735 | 38 | 152 |

A screenshot of a computer

Description automatically generated with medium confidenceA screenshot of a computer

Description automatically generated with low confidence

**Fig. S-13.** Performance of MFO-DT models.