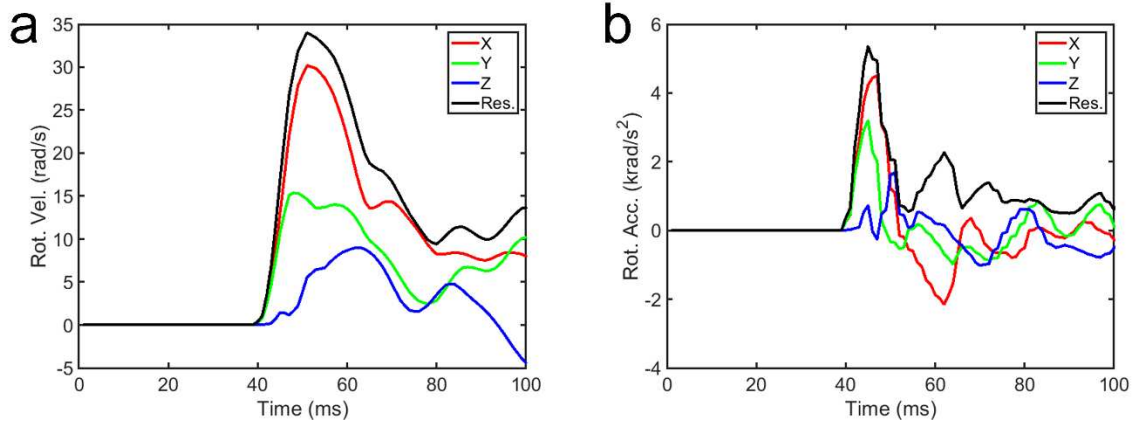


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4 903 **Supplementary materials:**

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7 904 **Fig. S1:** impact kinematic profiles for a selected case used in cross-validation.

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9 905 **Fig. S2:** impact kinematic profiles for a selected case used in independent testing.

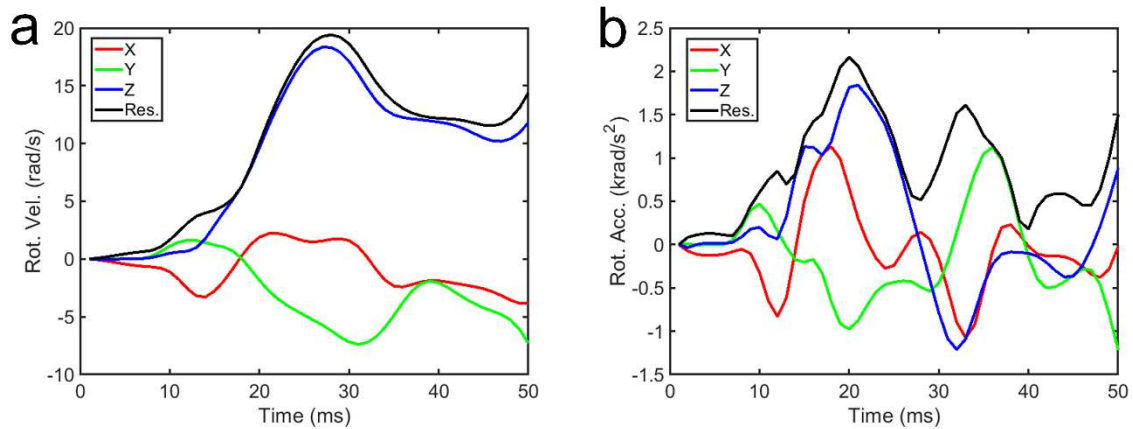
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12 906 **Fig. S3–S5:** Performances for 11 independent test cases from various published sources.



907

908 **Fig. S1.** (a) v_{rot} and (b) a_{rot} profiles for a representative impact used to cross-validate displacement
909 prediction performance of the TNN/CNN models shown in **Fig. 8** in the main paper.

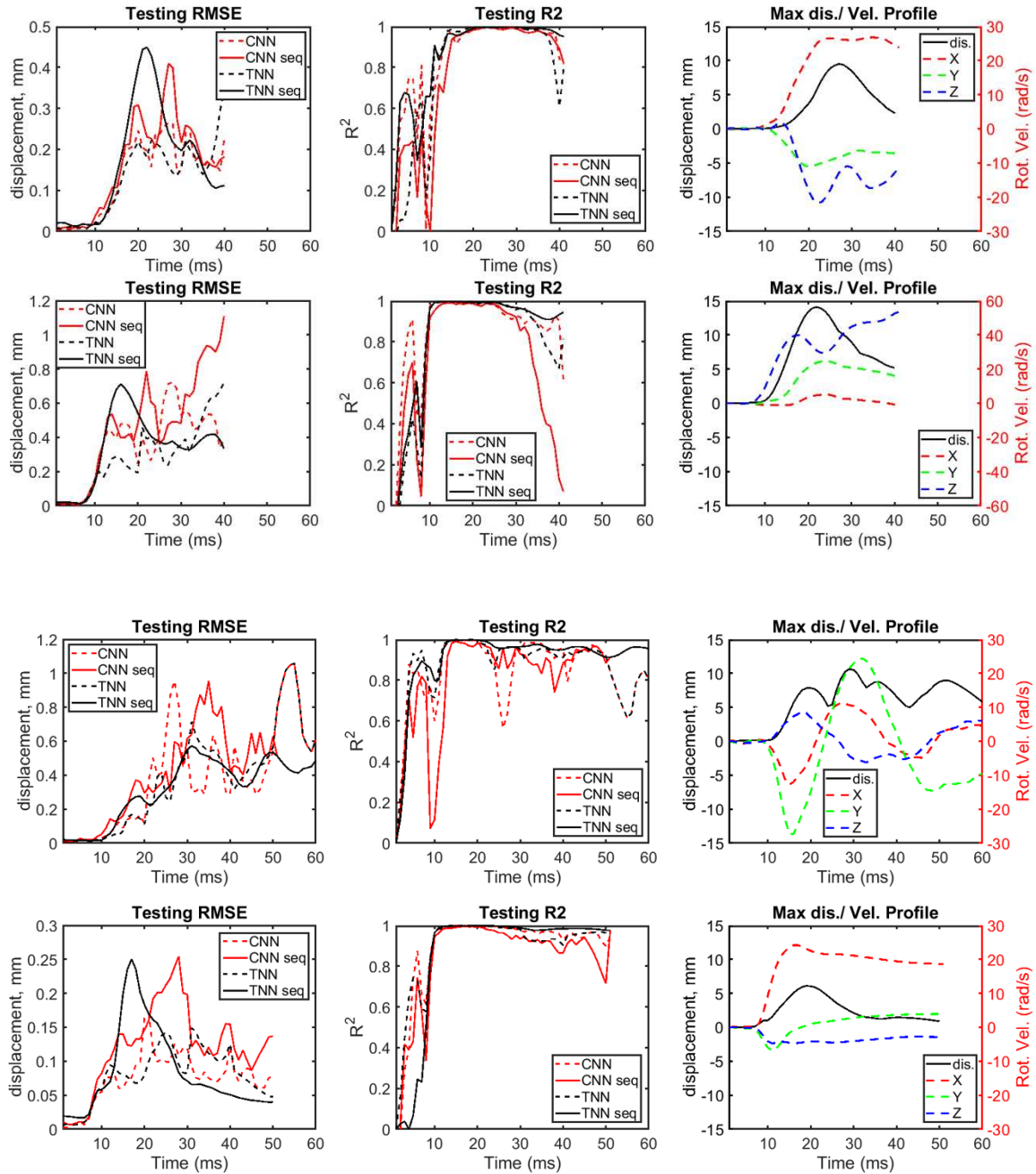
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911

912 **Fig. S2.** (a) v_{rot} and (b) a_{rot} profiles for a representative impact in the independent testing dataset used to
913 evaluate displacement prediction performances of the TNN/CNN models shown in **Fig. 10** in the main paper.

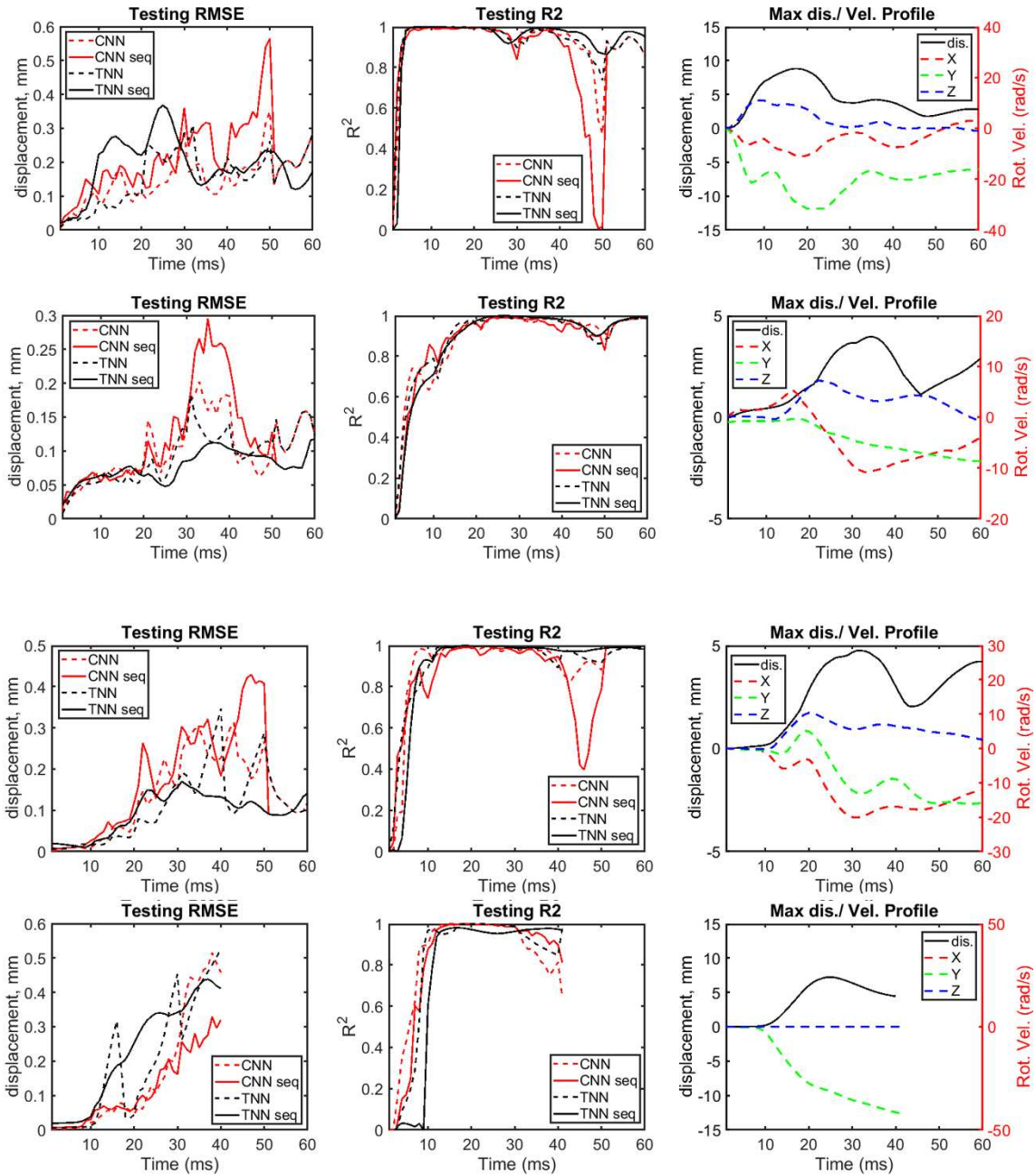
914 The profiles were further shifted and padded before serving as input to the TNN/CNN for displacement
 915 estimation.



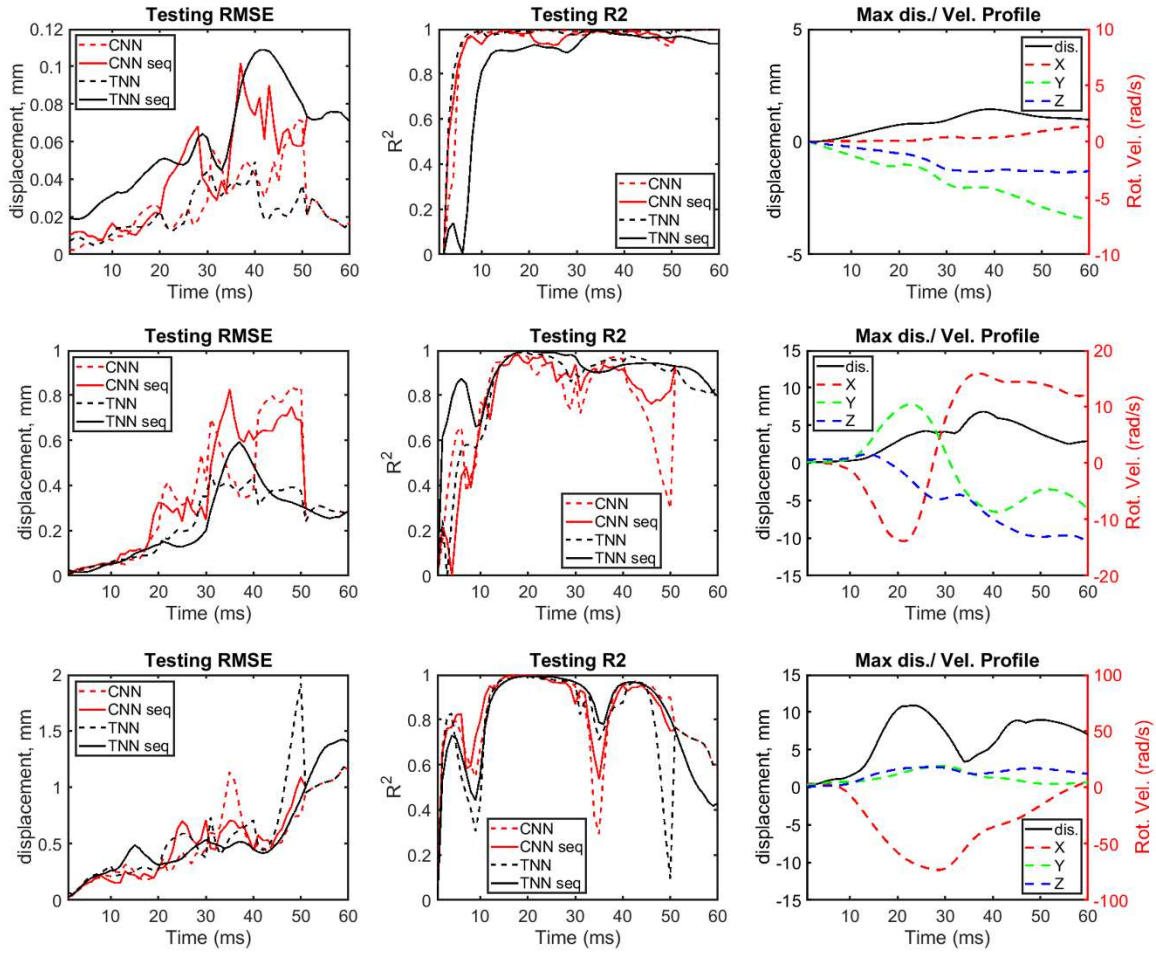
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918 **Fig. S3.** Performance comparisons among TNN/CNN baseline and sequential training strategies in terms of
 919 RMSE and R^2 for selected impact Cases 1 through 4 (Table 3). The corresponding maximum displacement
 920 magnitude over time is also provided together with the three rotational velocity components.



923 **Fig. S4.** Performance comparisons among TNN/CNN baseline and sequential training strategies in terms of
 924 RMSE and R^2 for selected impact Cases 5 through 8 (Table 3). The corresponding maximum displacement
 925 magnitude over time is also provided together with the three rotational velocity components.



926

927 **Fig. S5.** Performance comparisons among TNN/CNN baseline and sequential training strategies in terms of
 928 RMSE and R^2 for selected impact Cases 9 through 11 (Table 3). The corresponding maximum displacement
 929 magnitude over time is also provided together with the three rotational velocity components.