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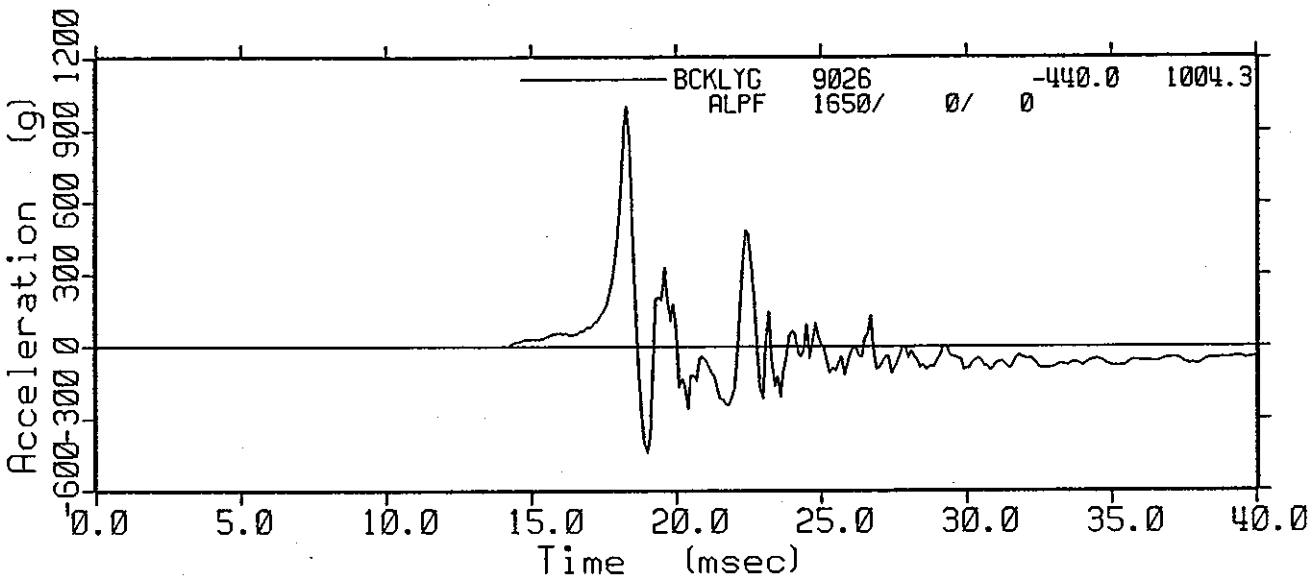

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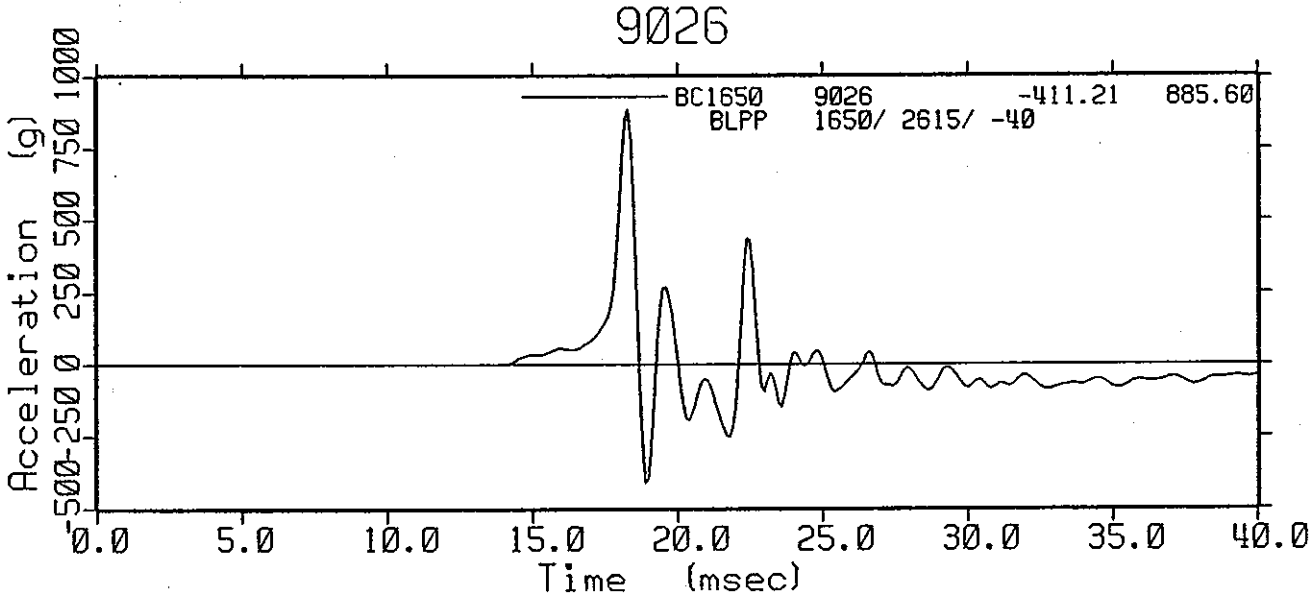

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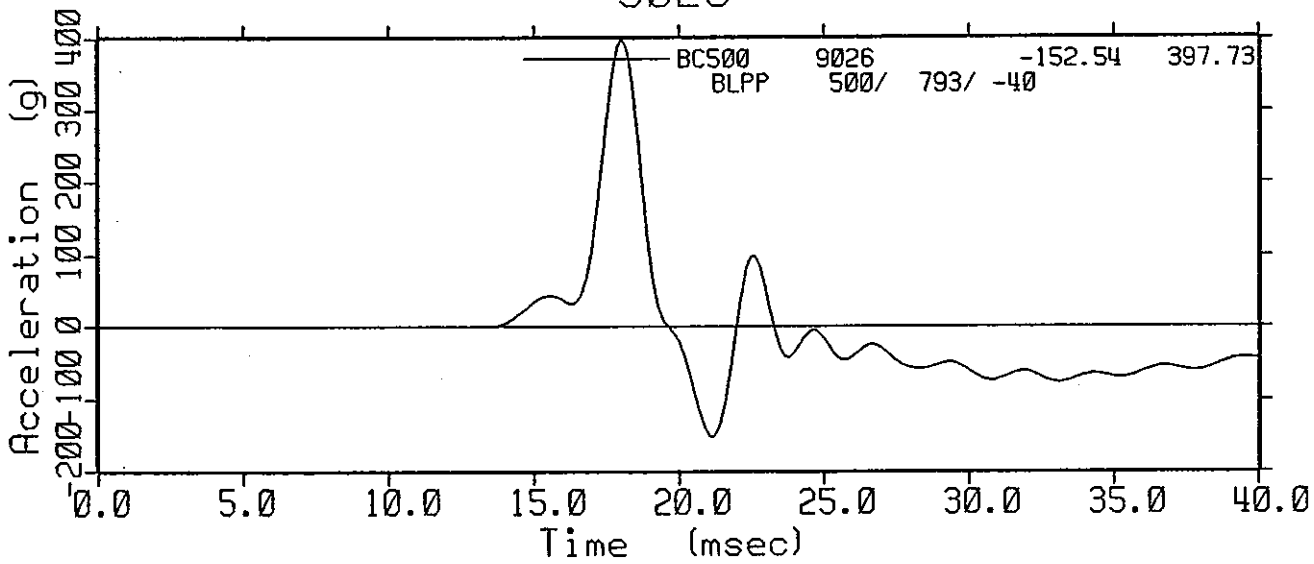

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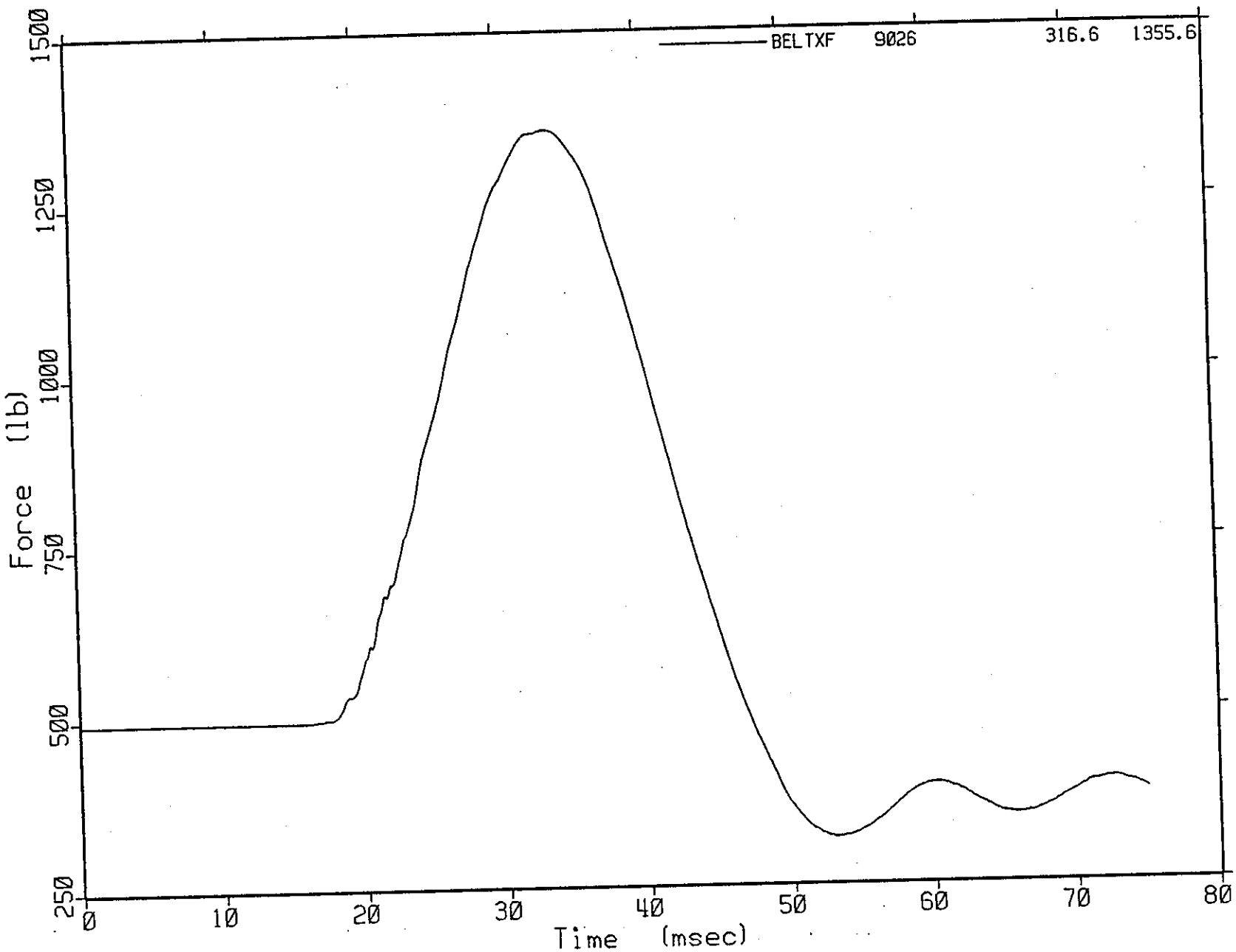

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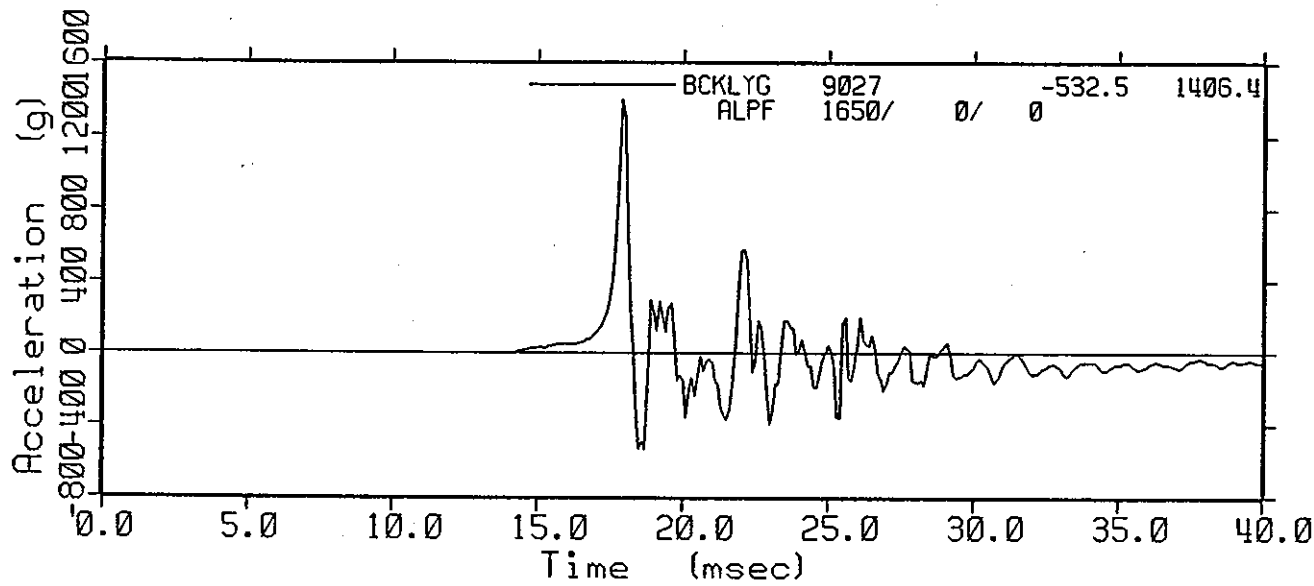

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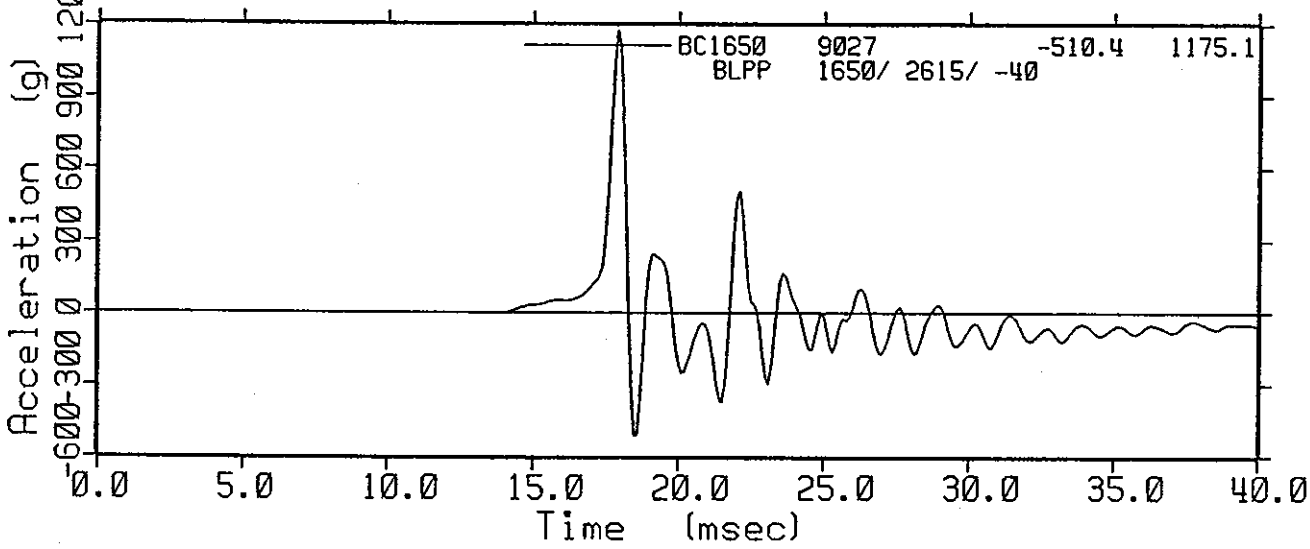

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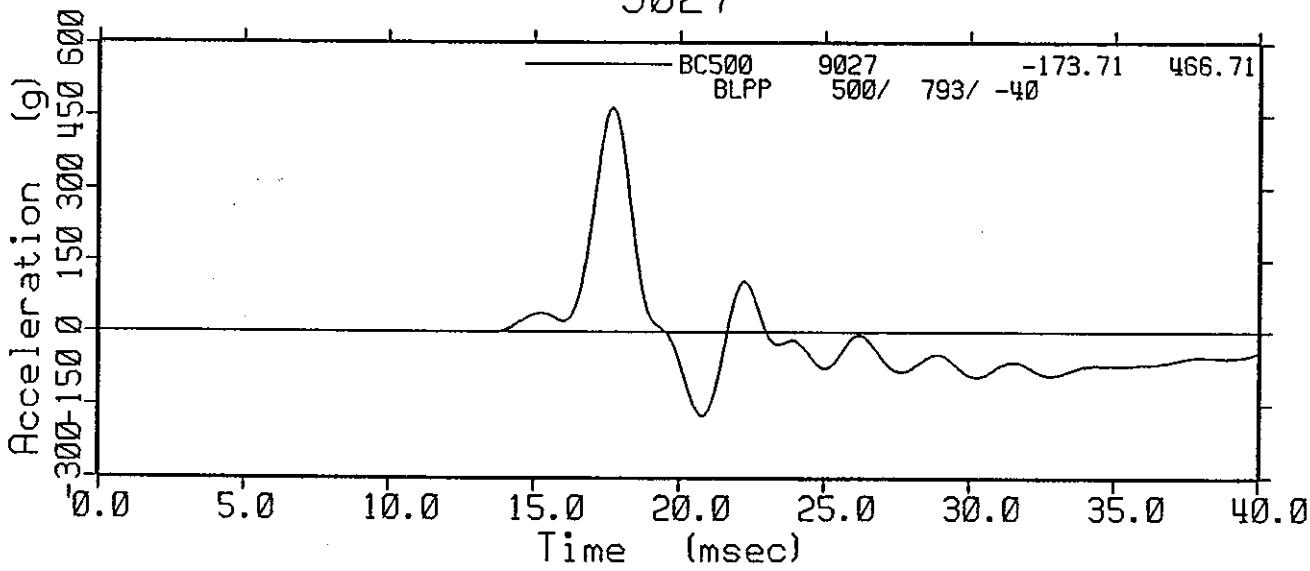

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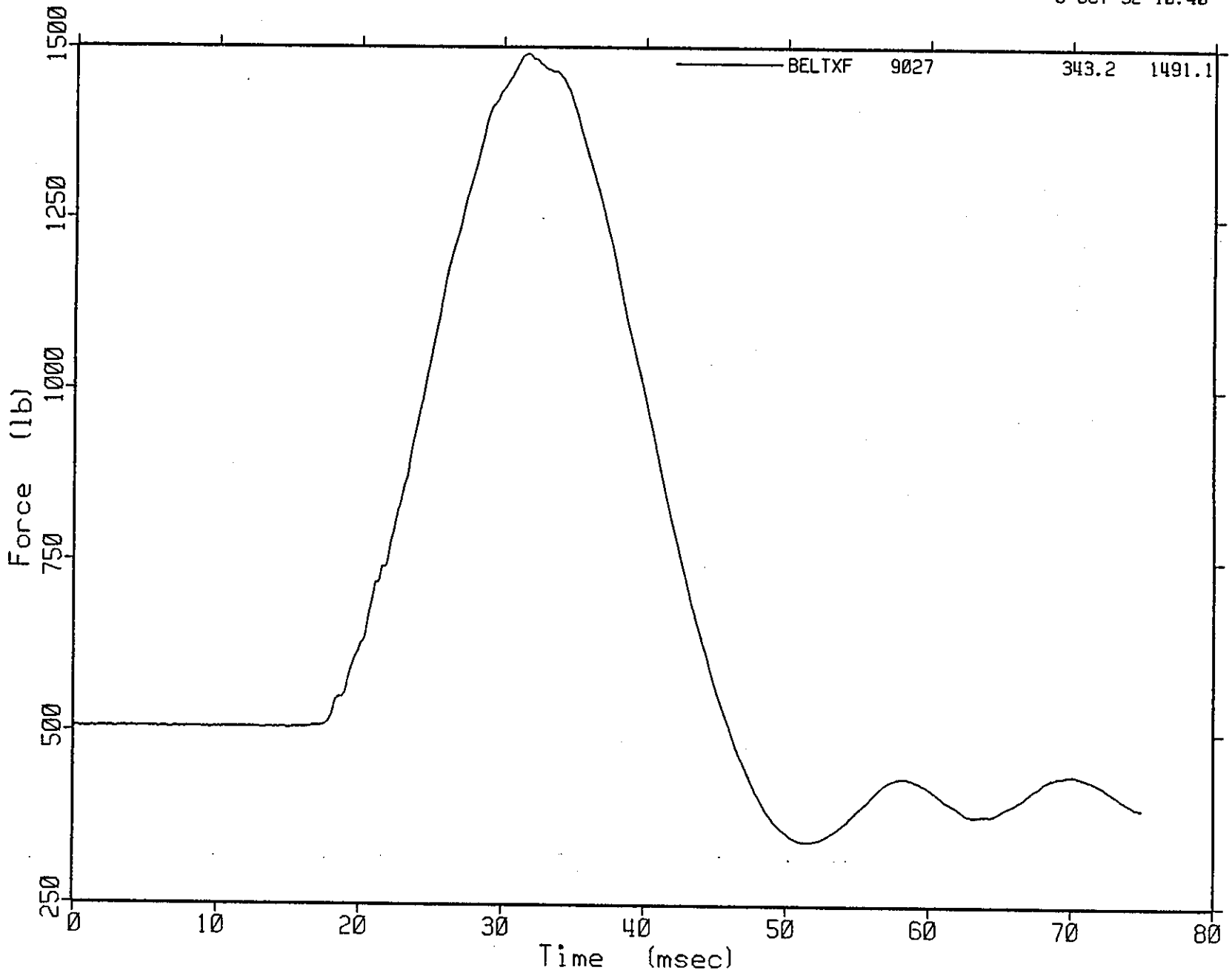

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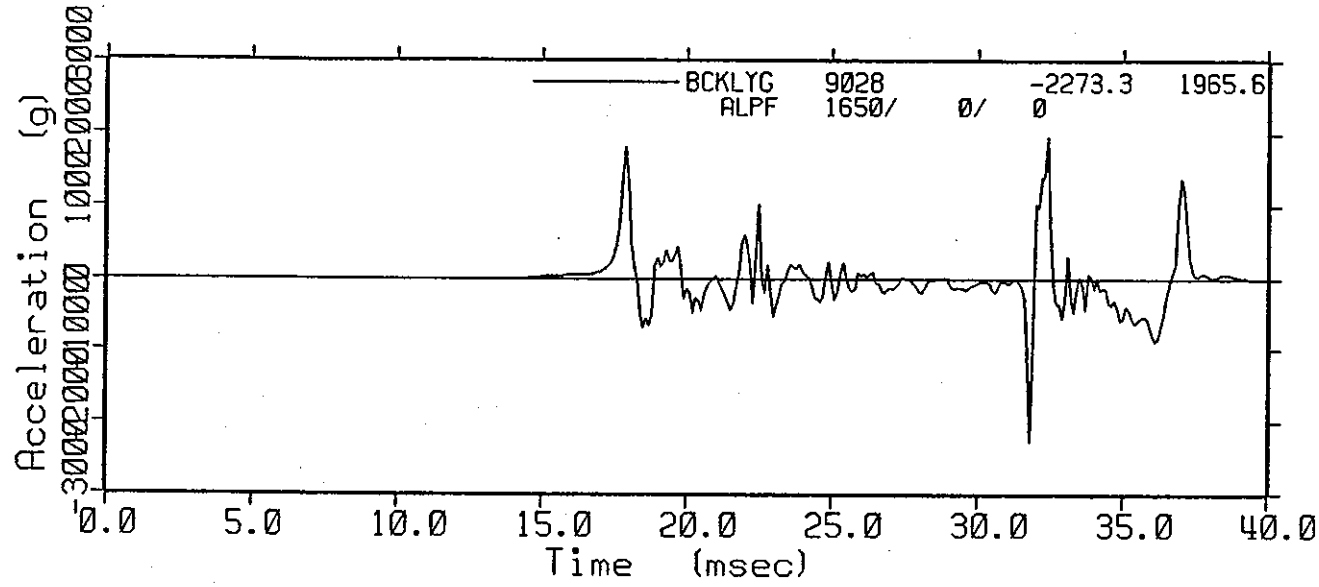

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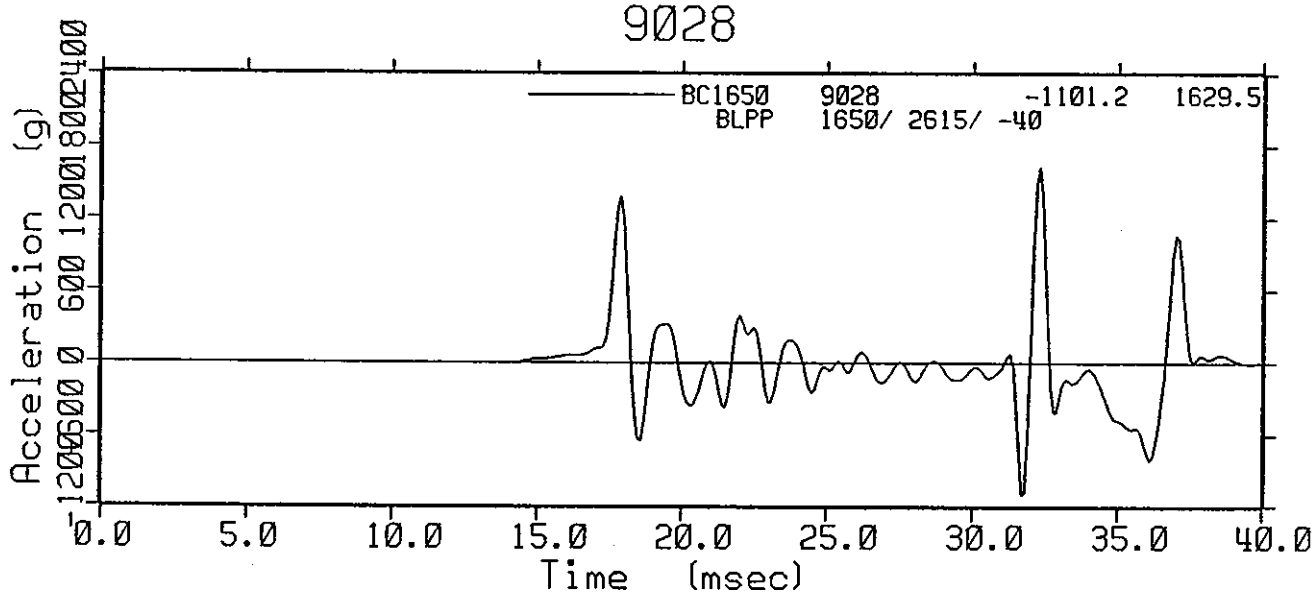

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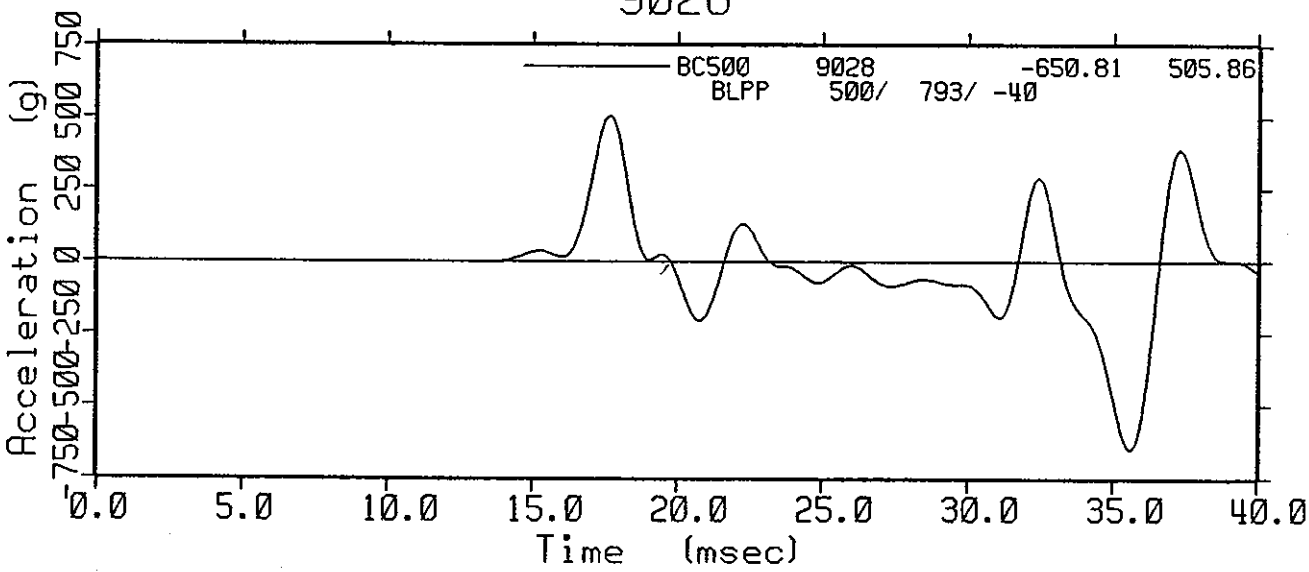

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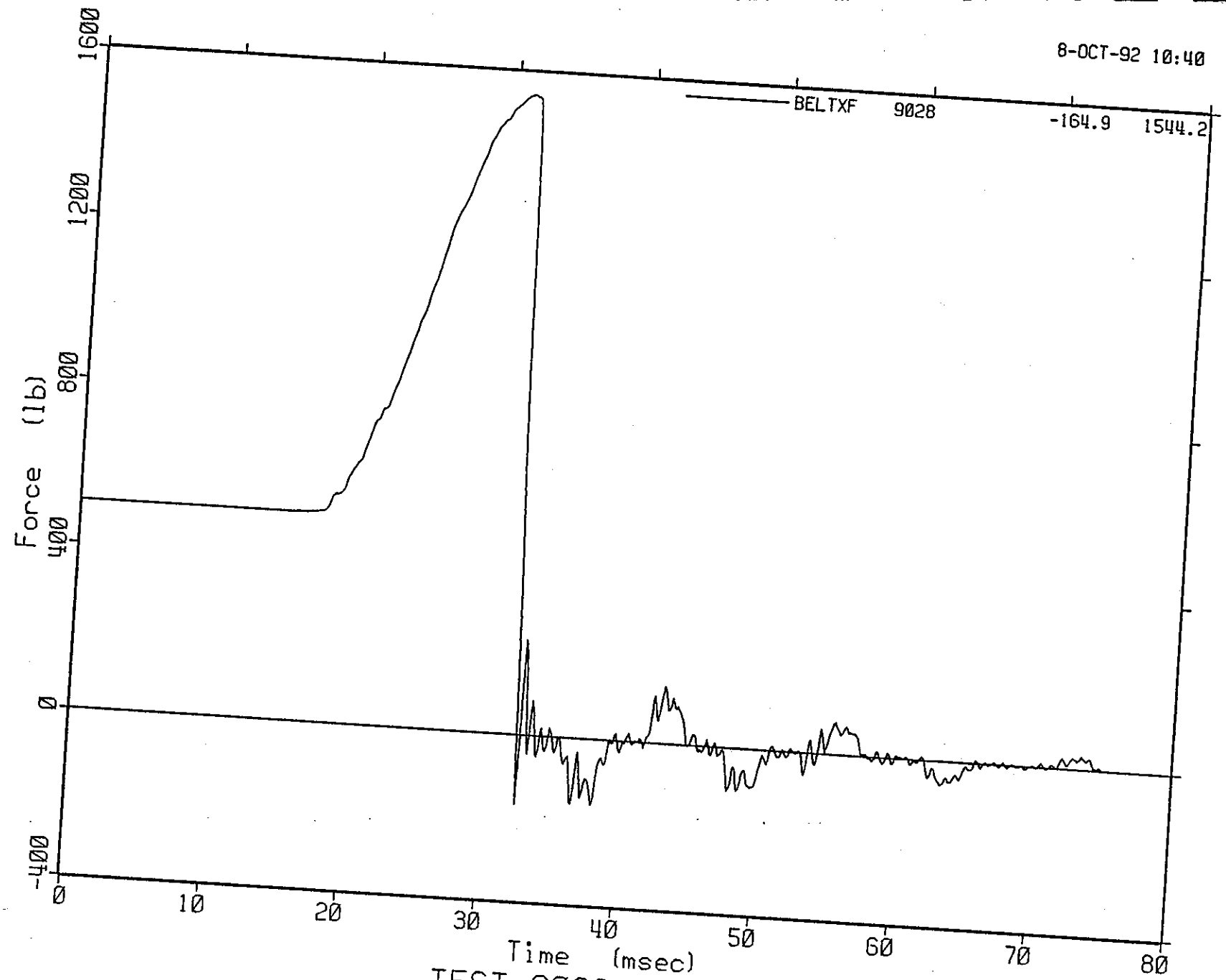

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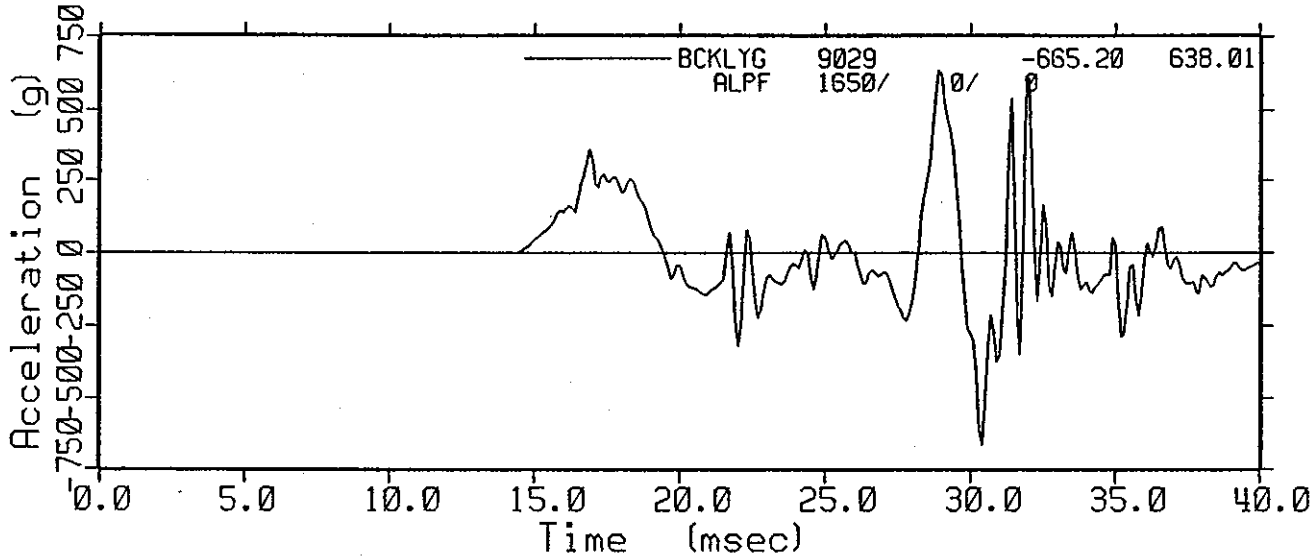

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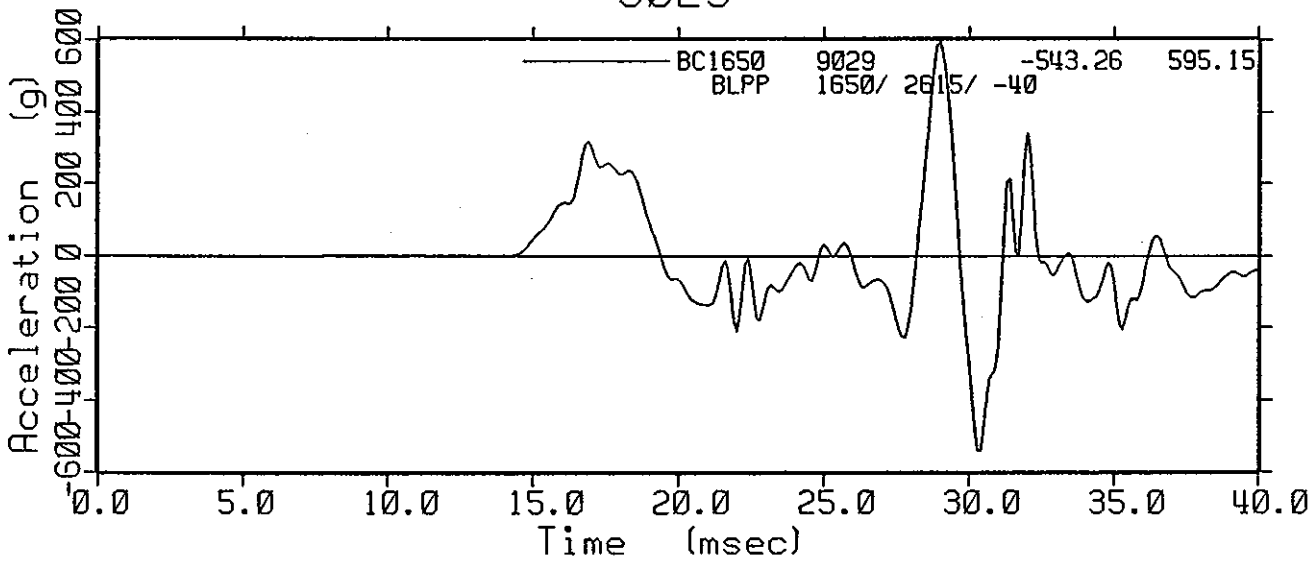

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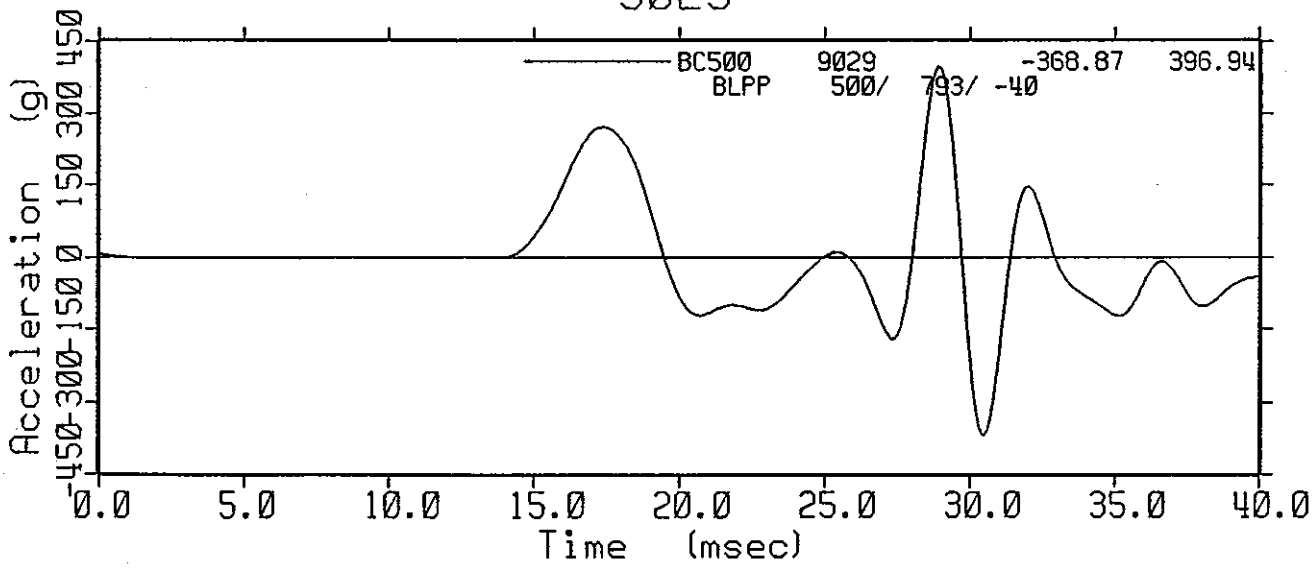

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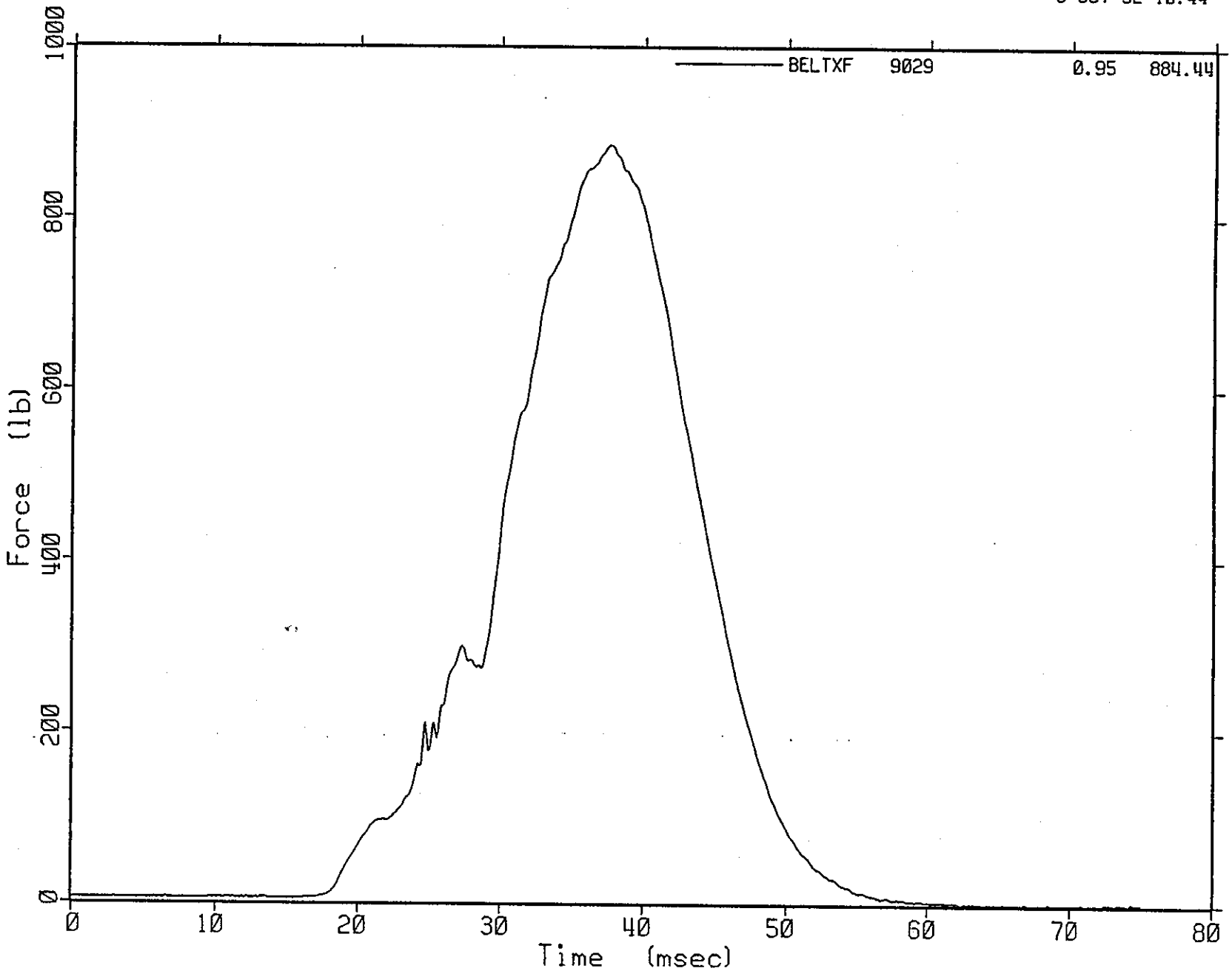

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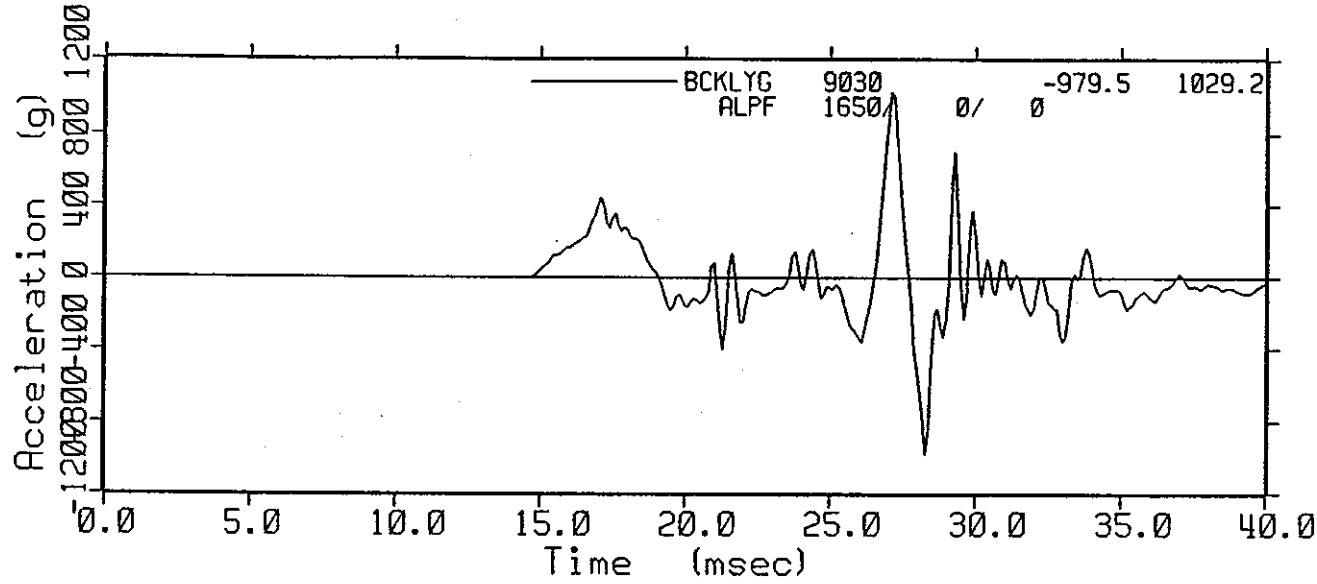

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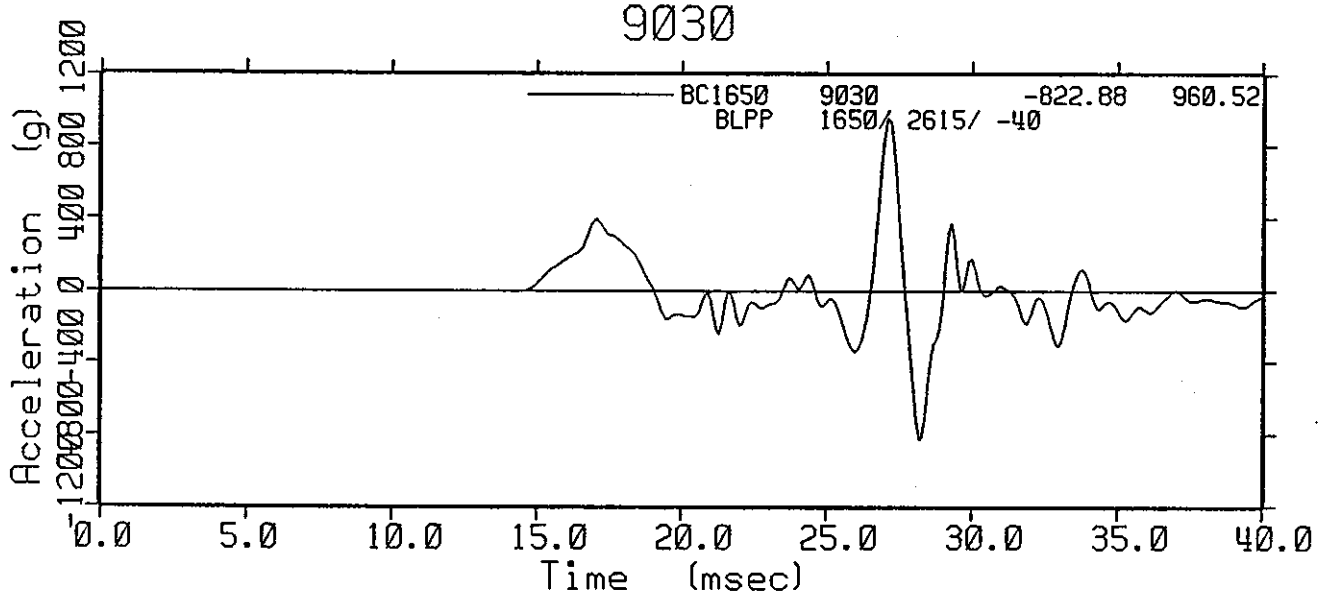

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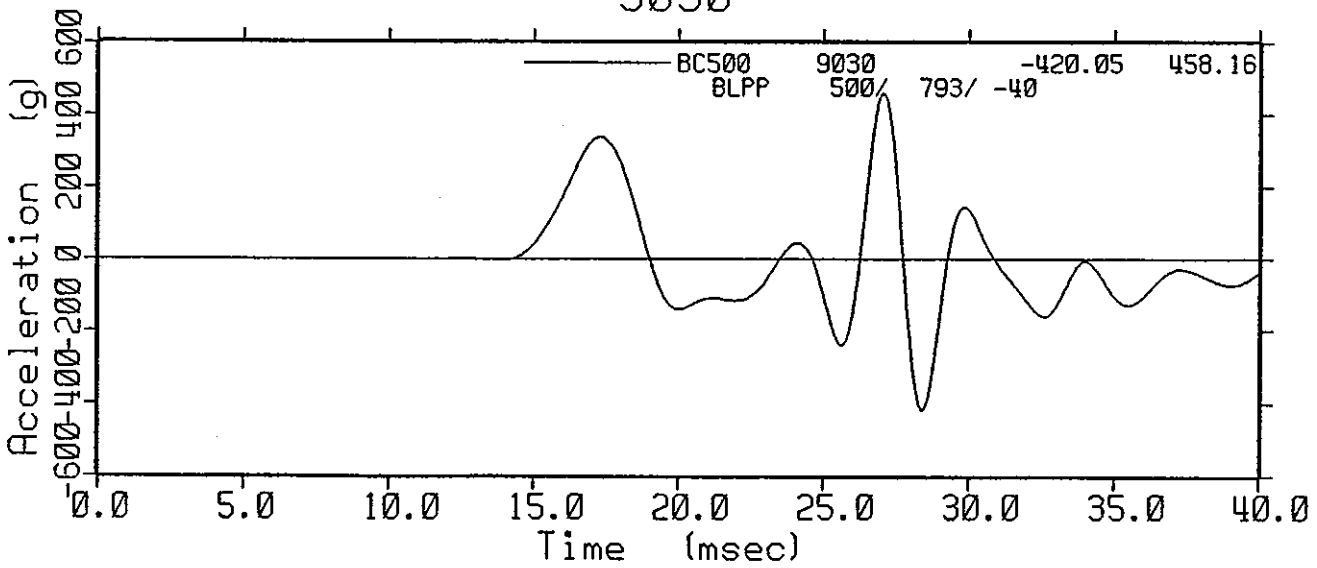

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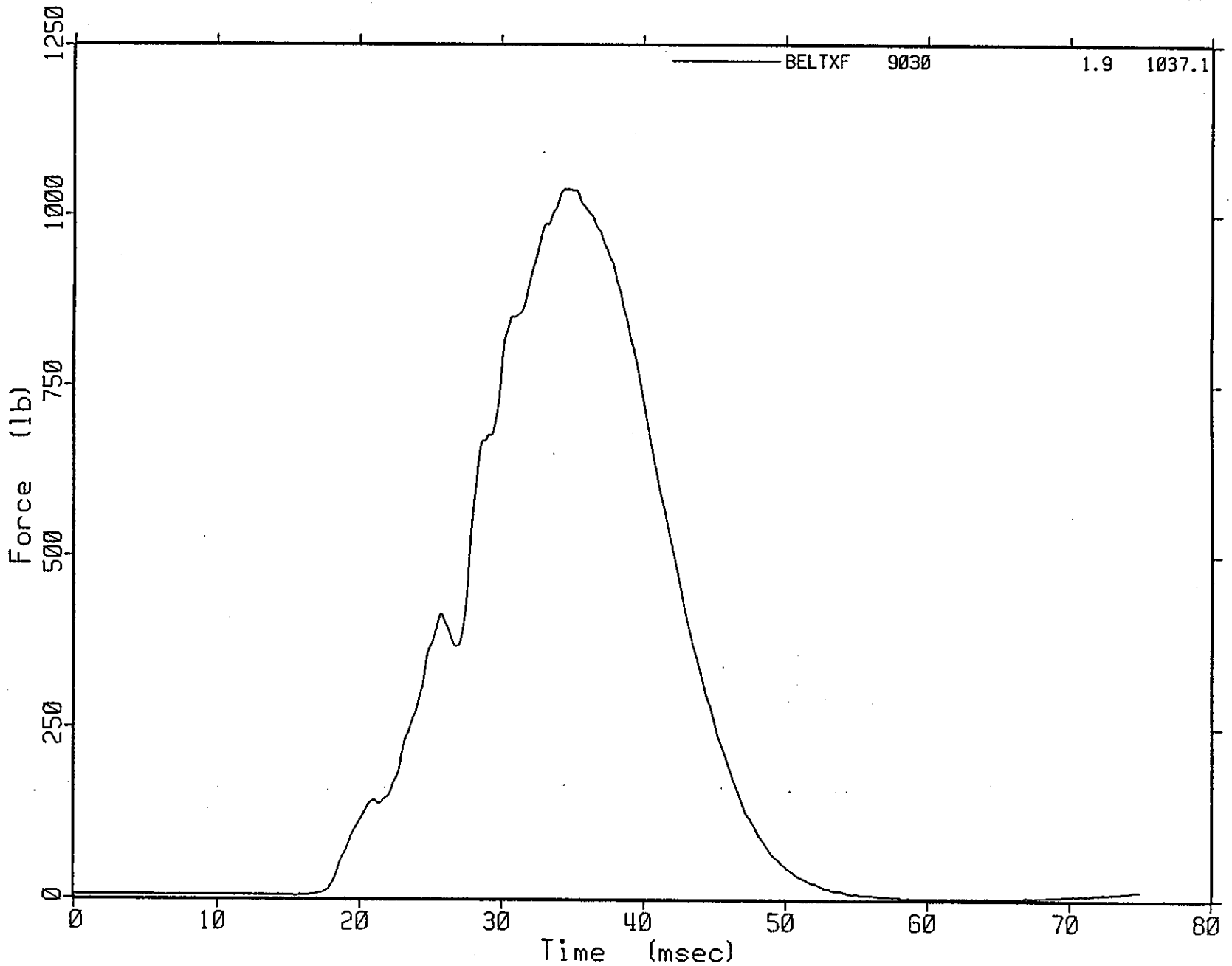

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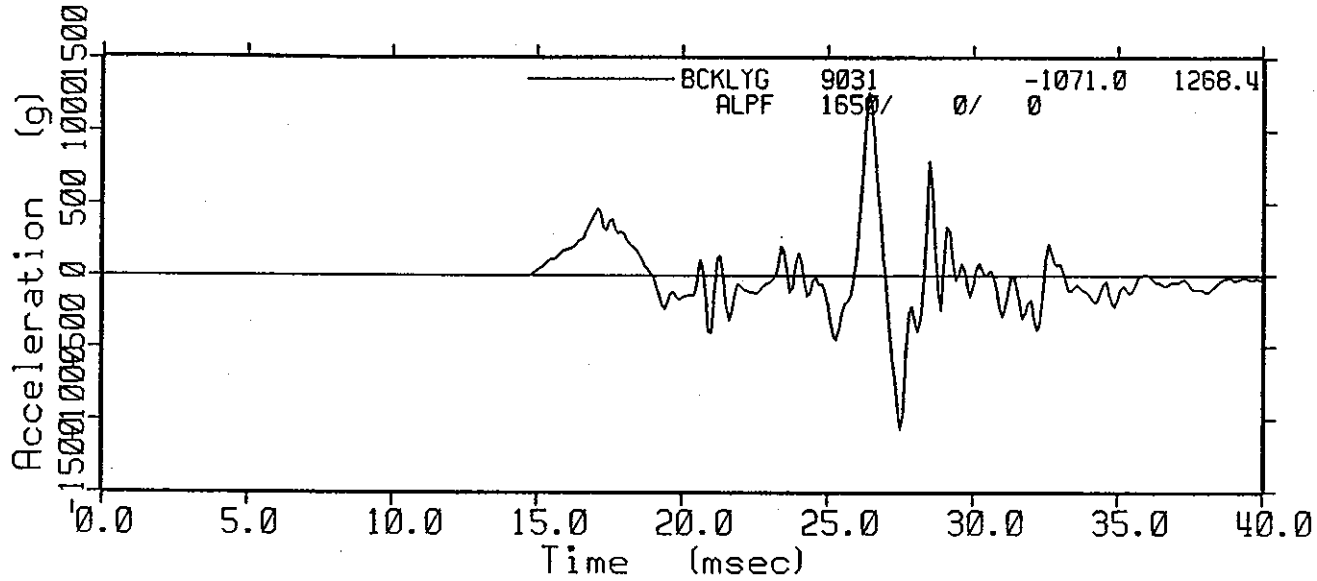

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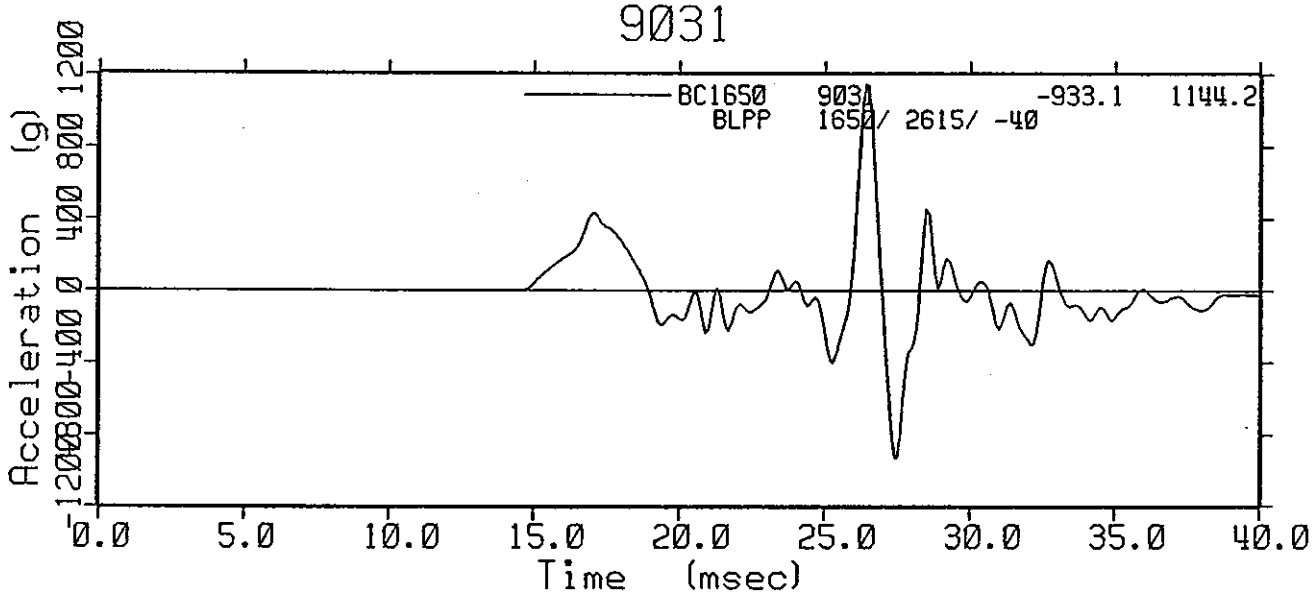

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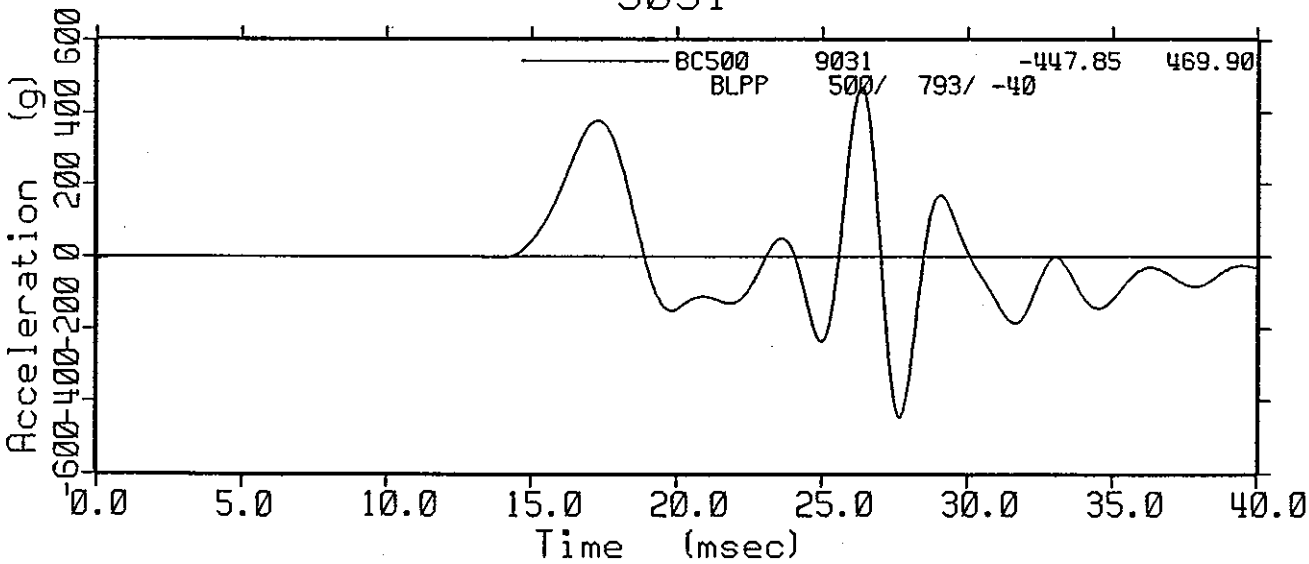

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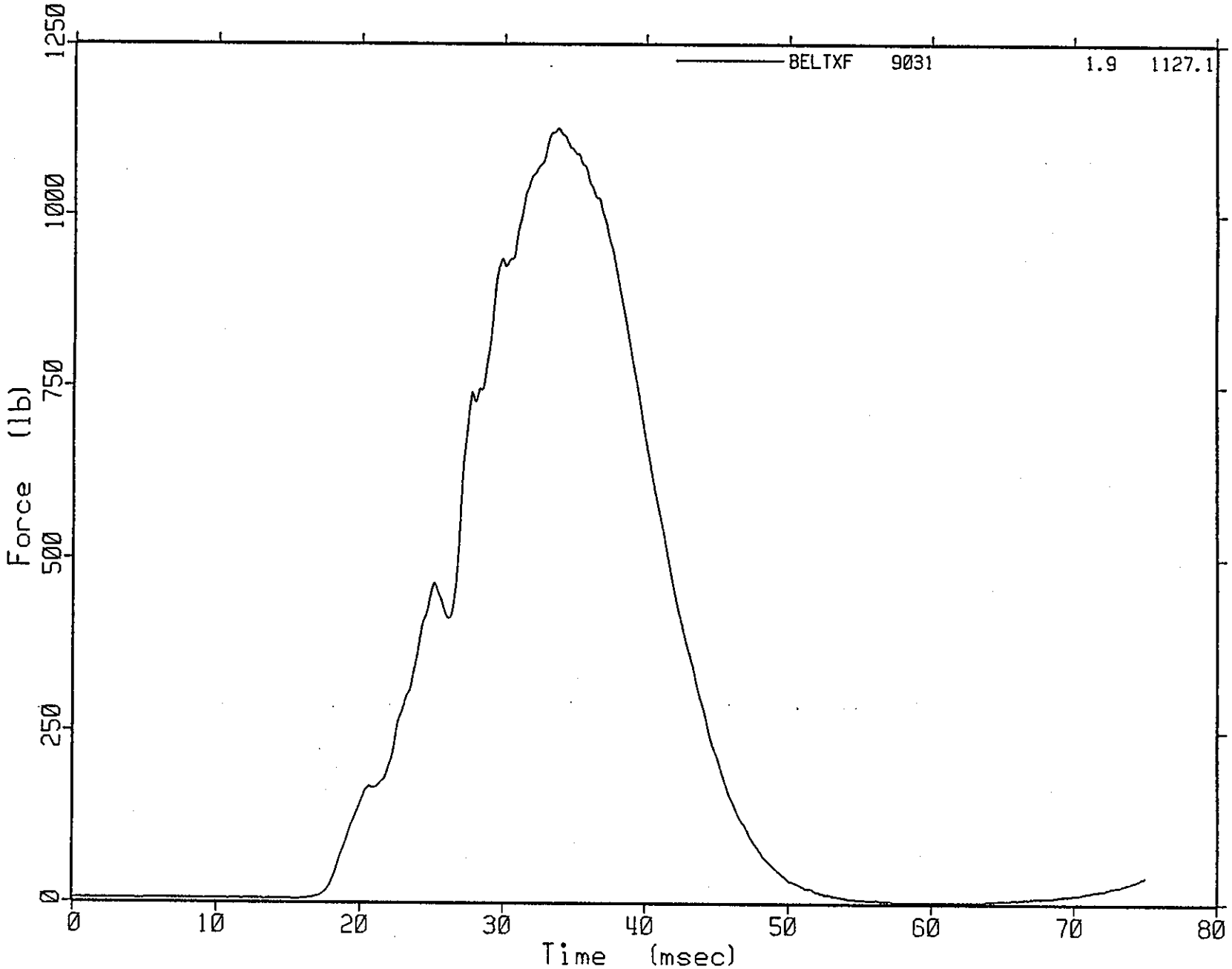

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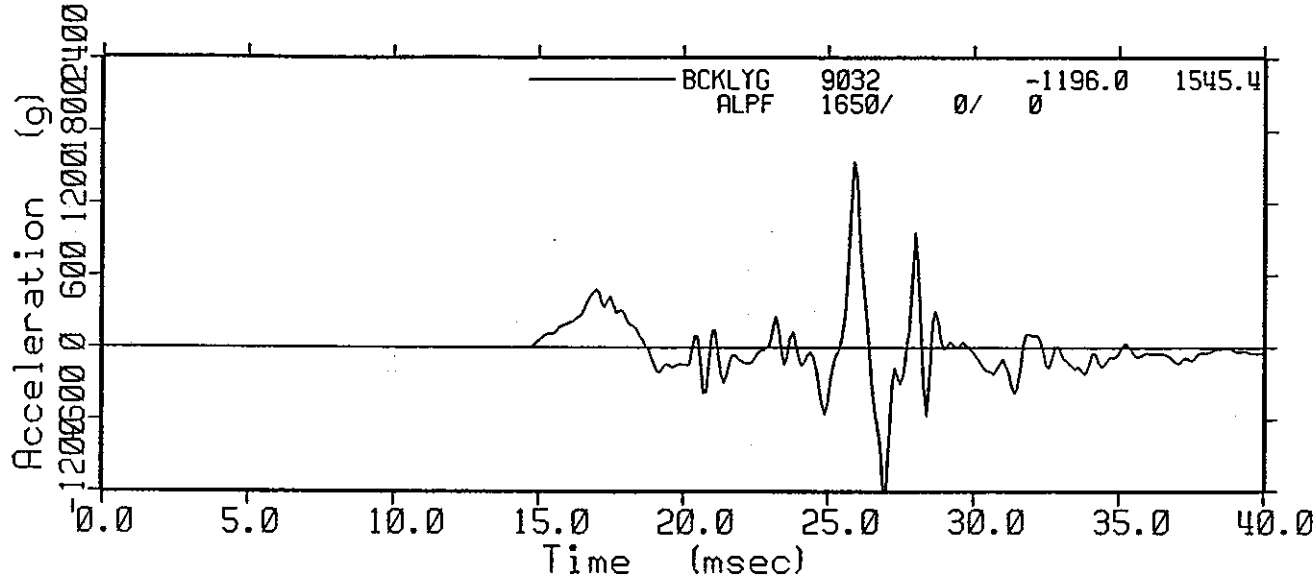

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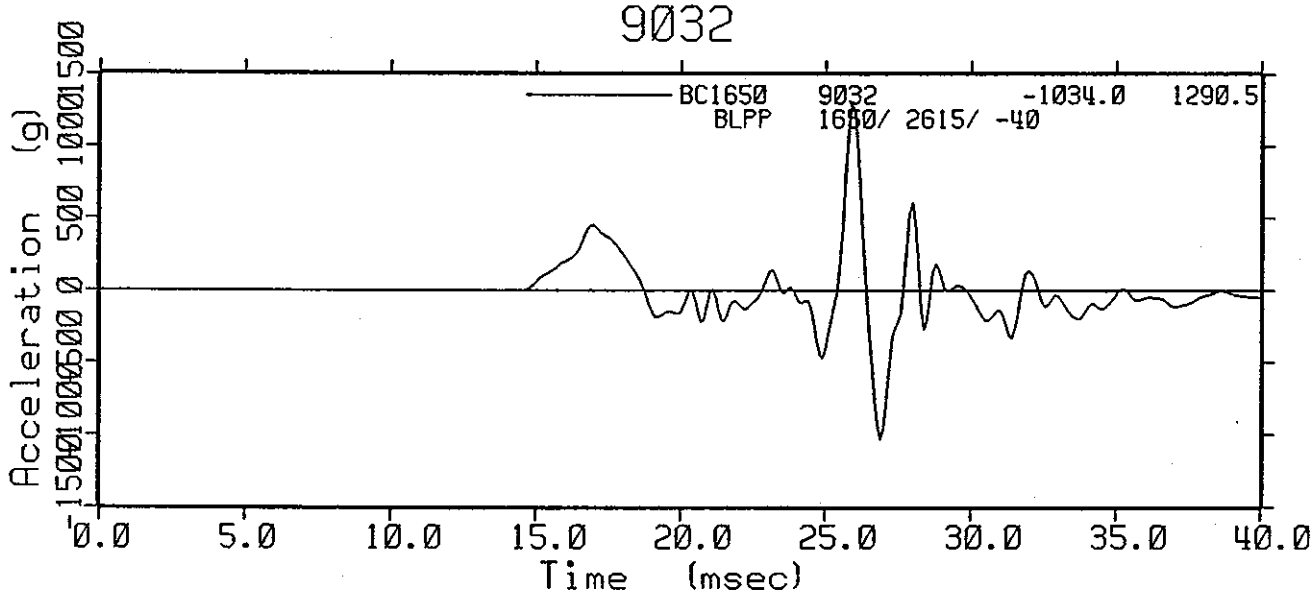

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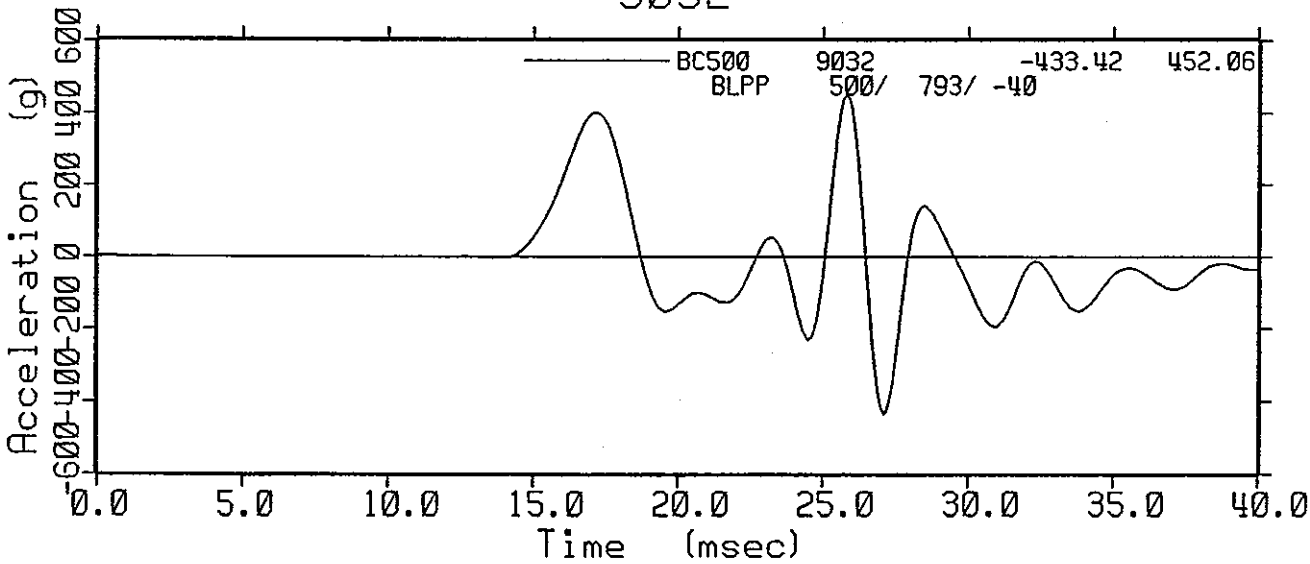

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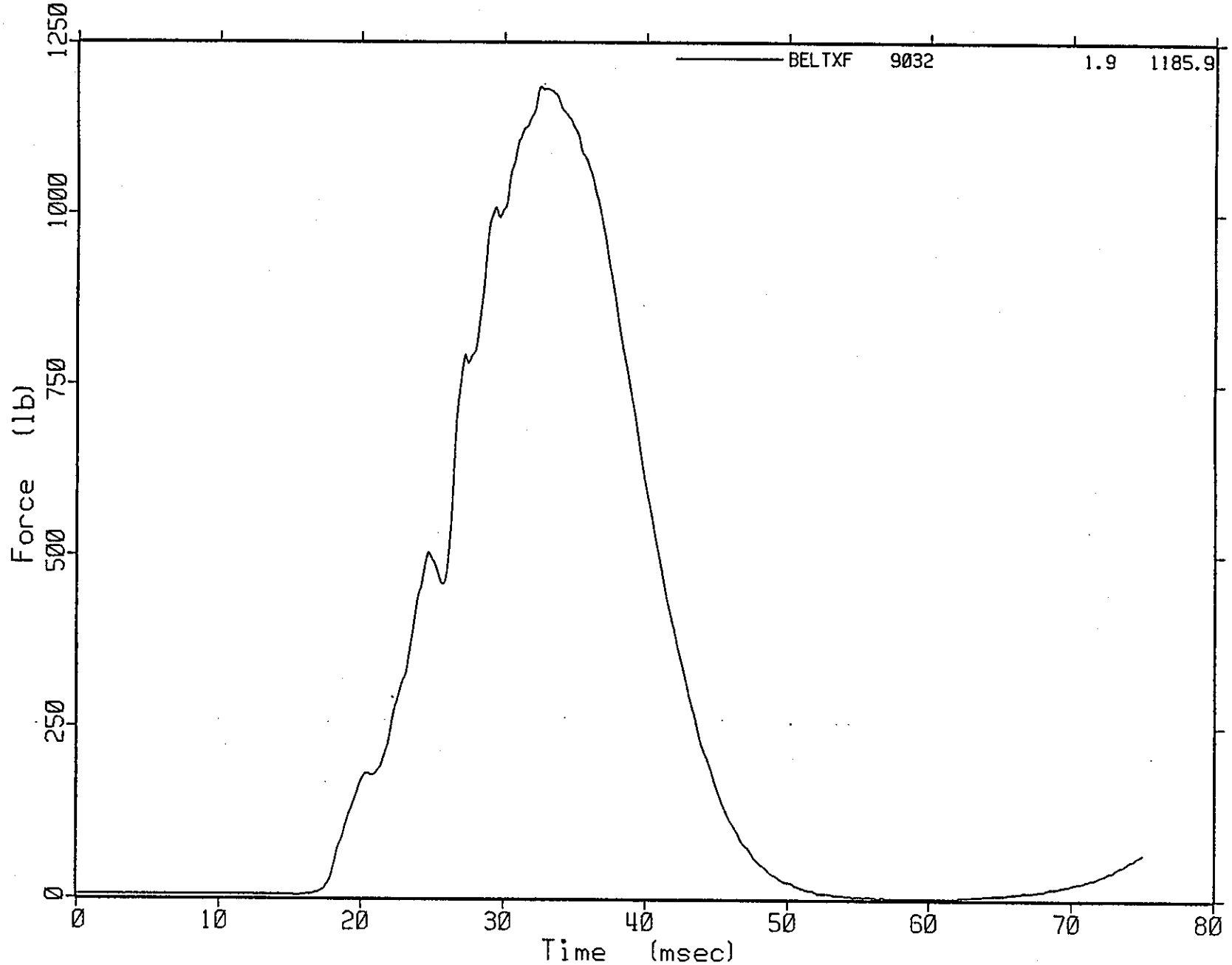

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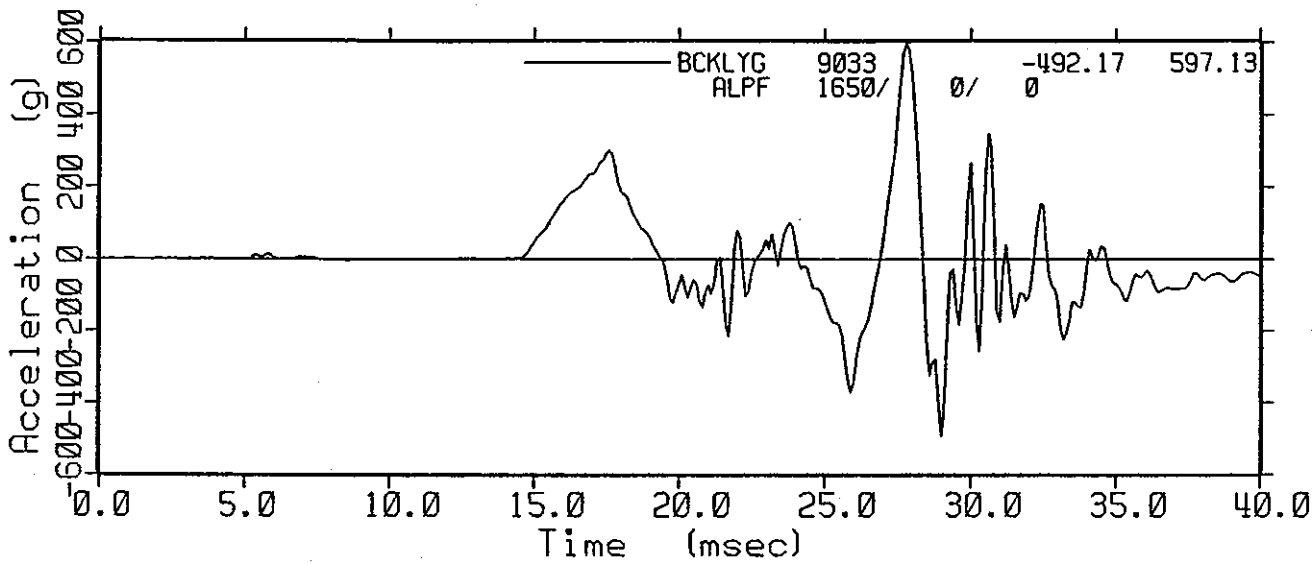

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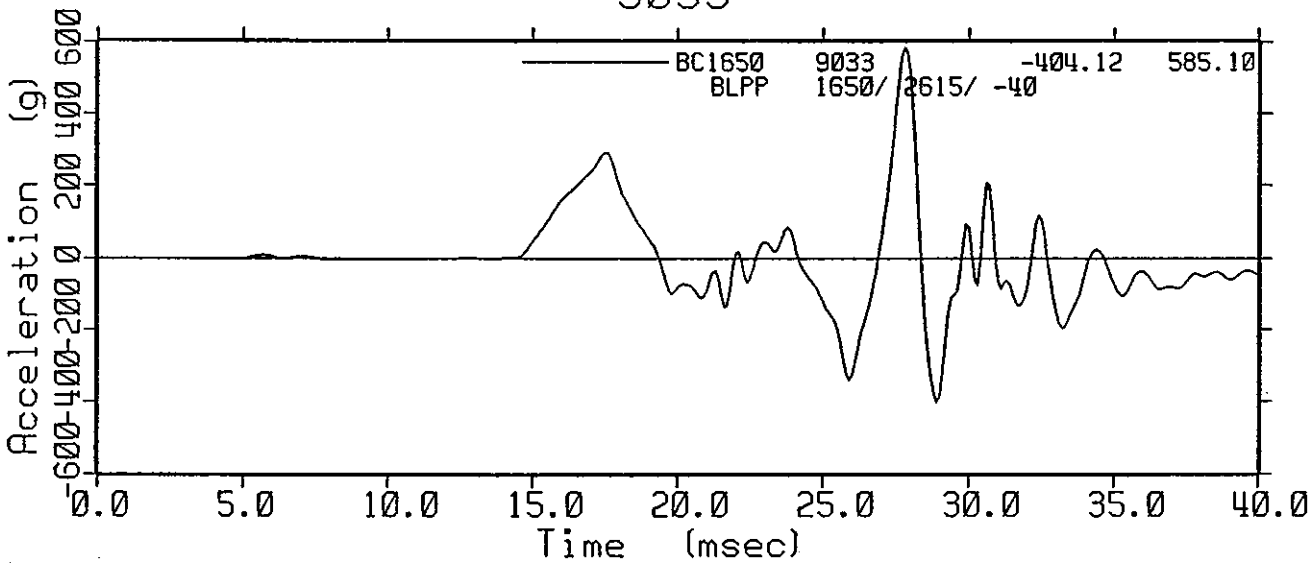

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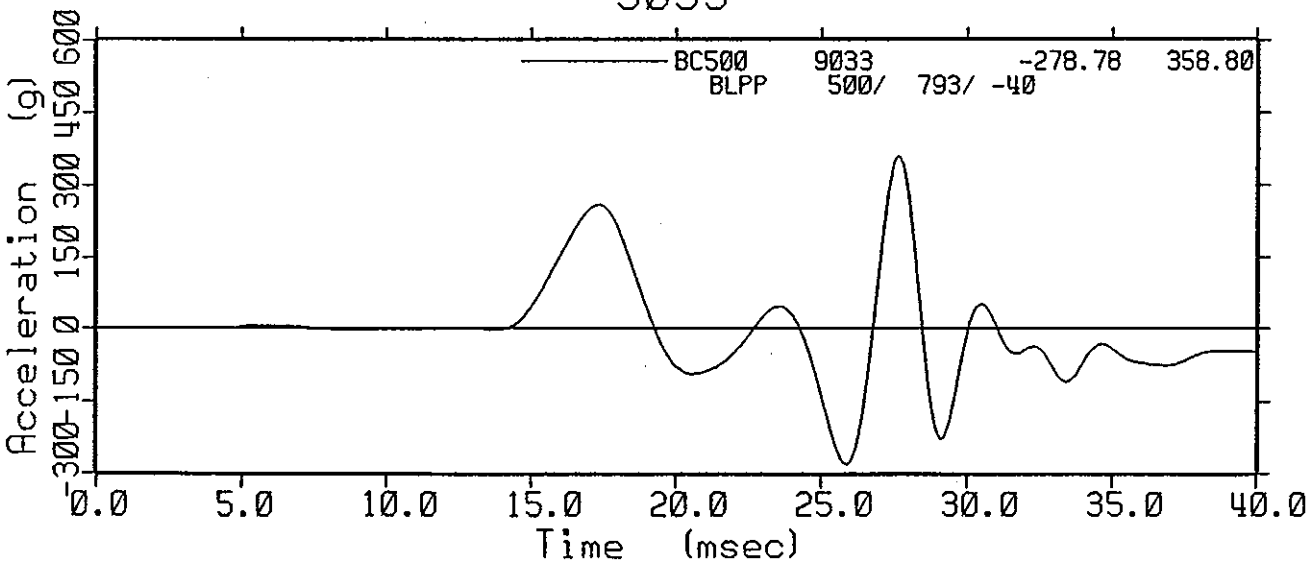

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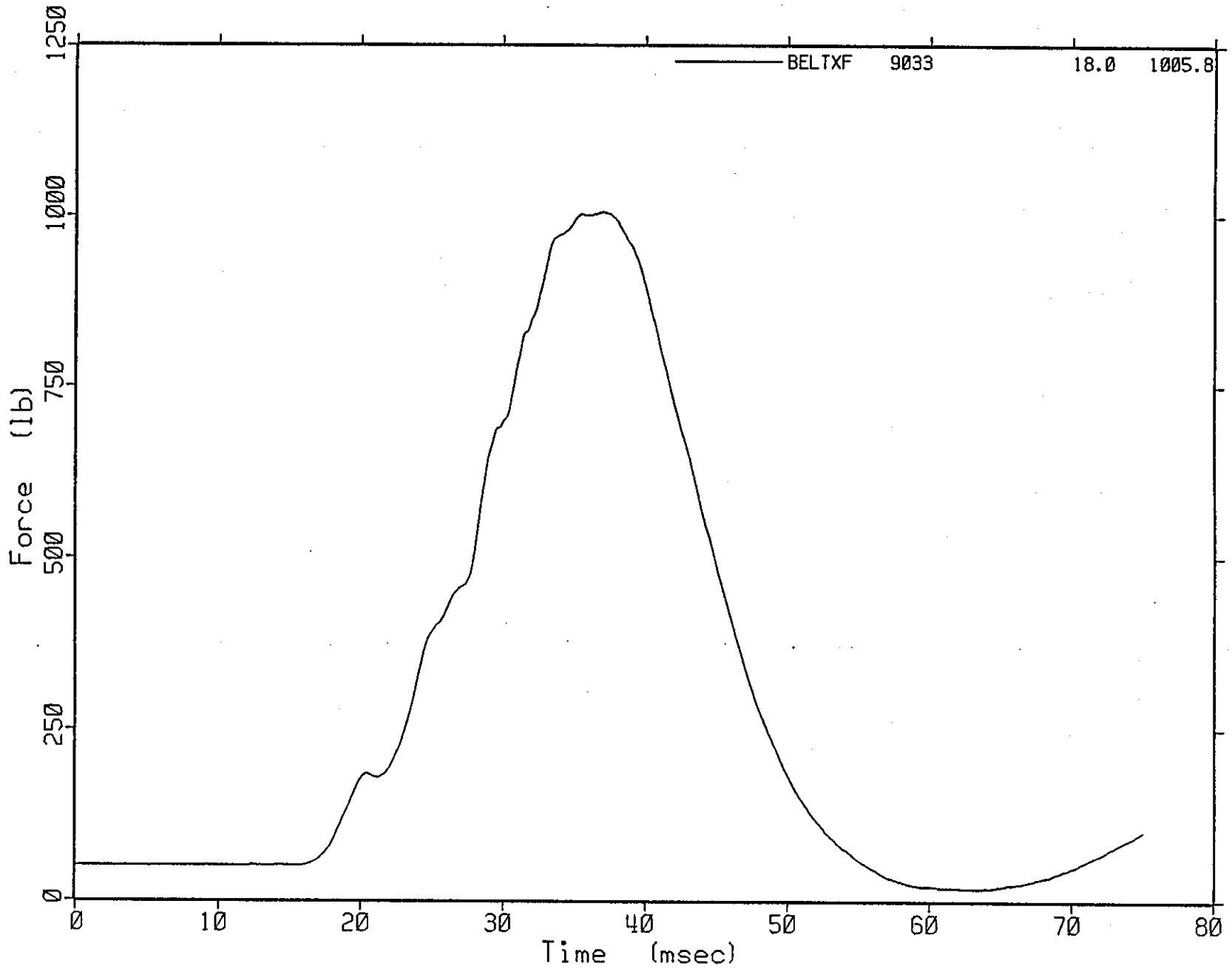

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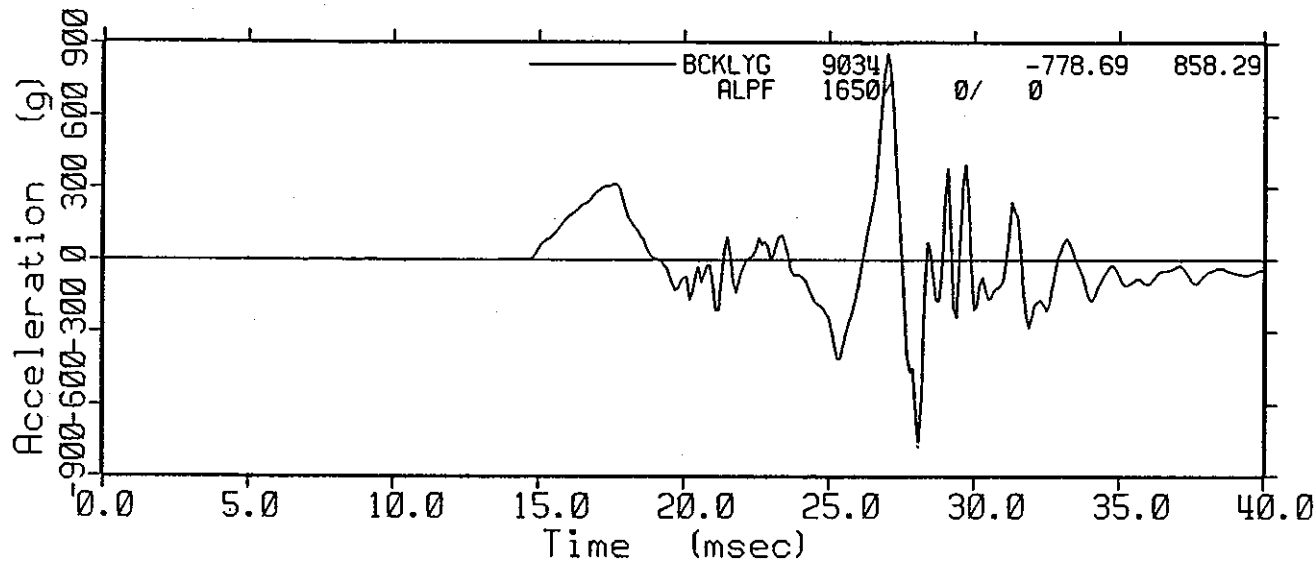

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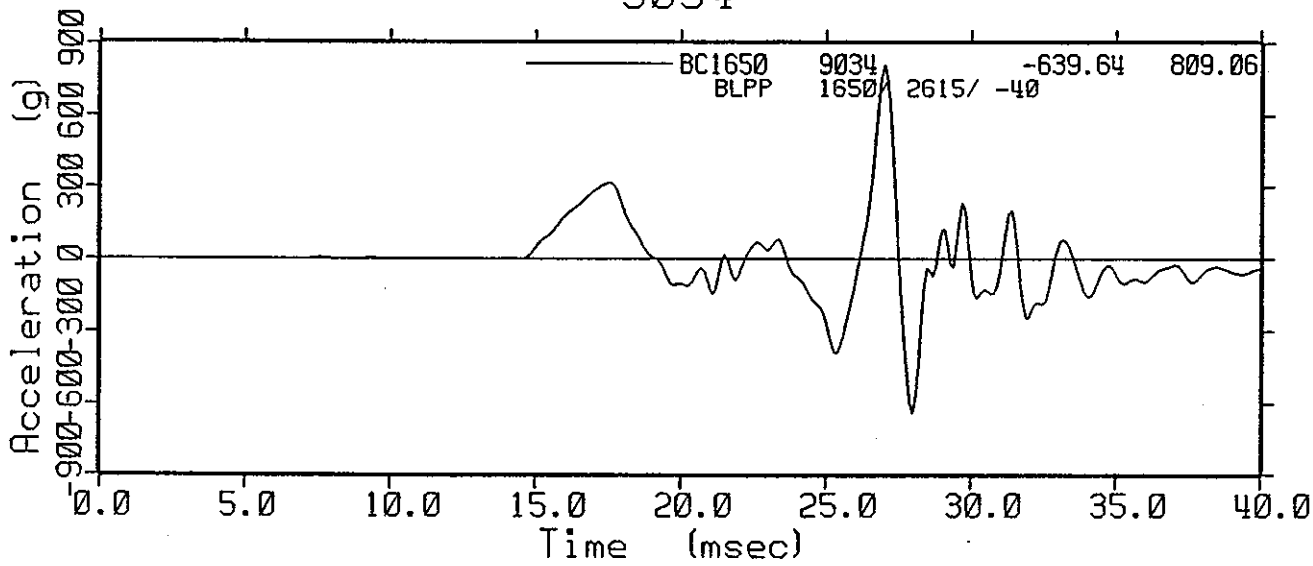

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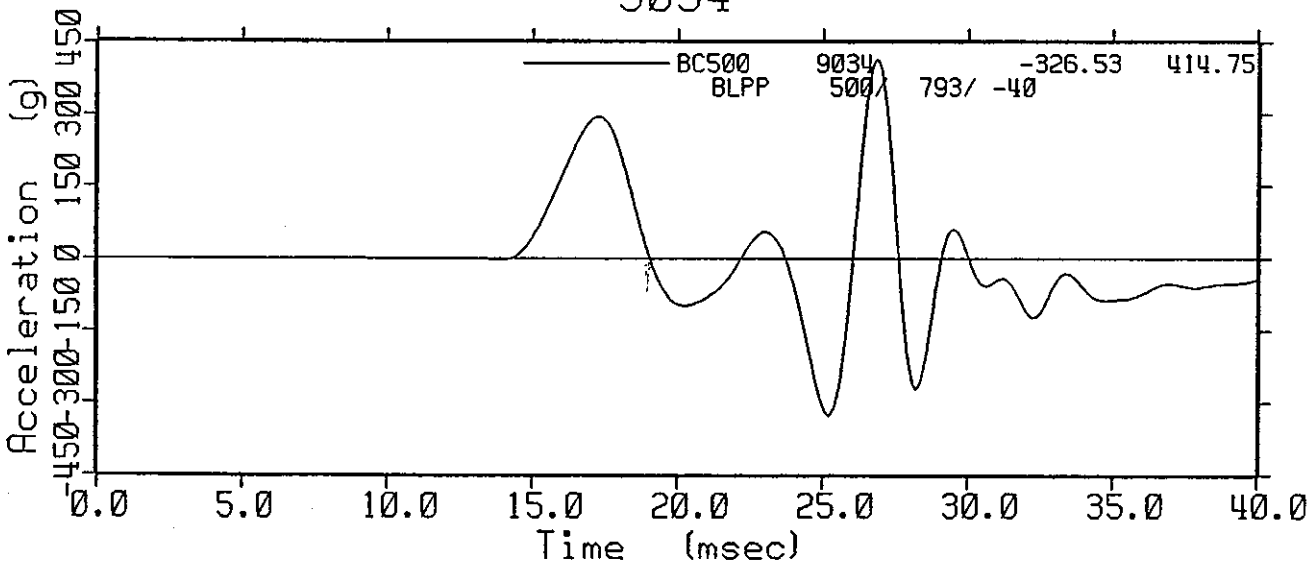

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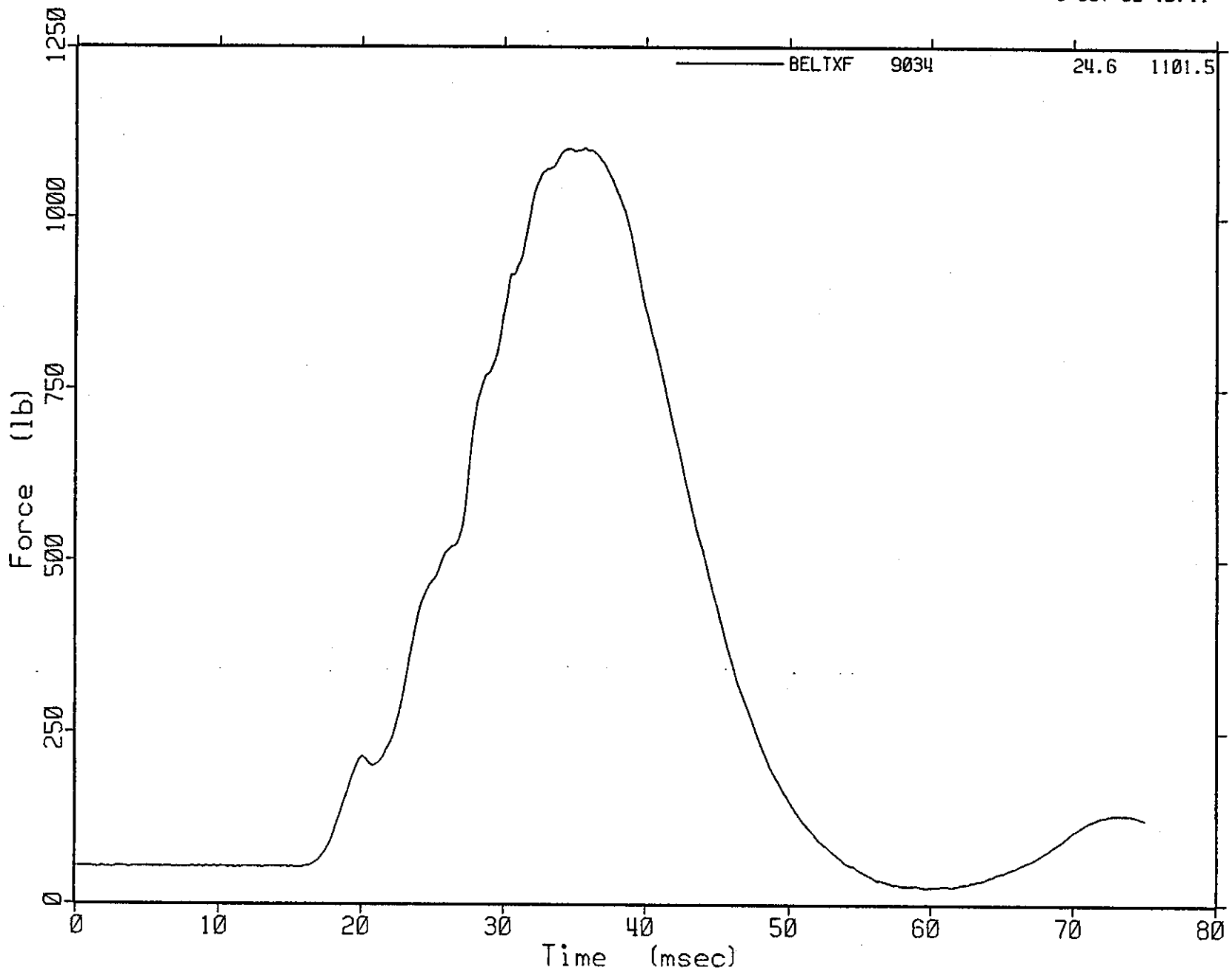

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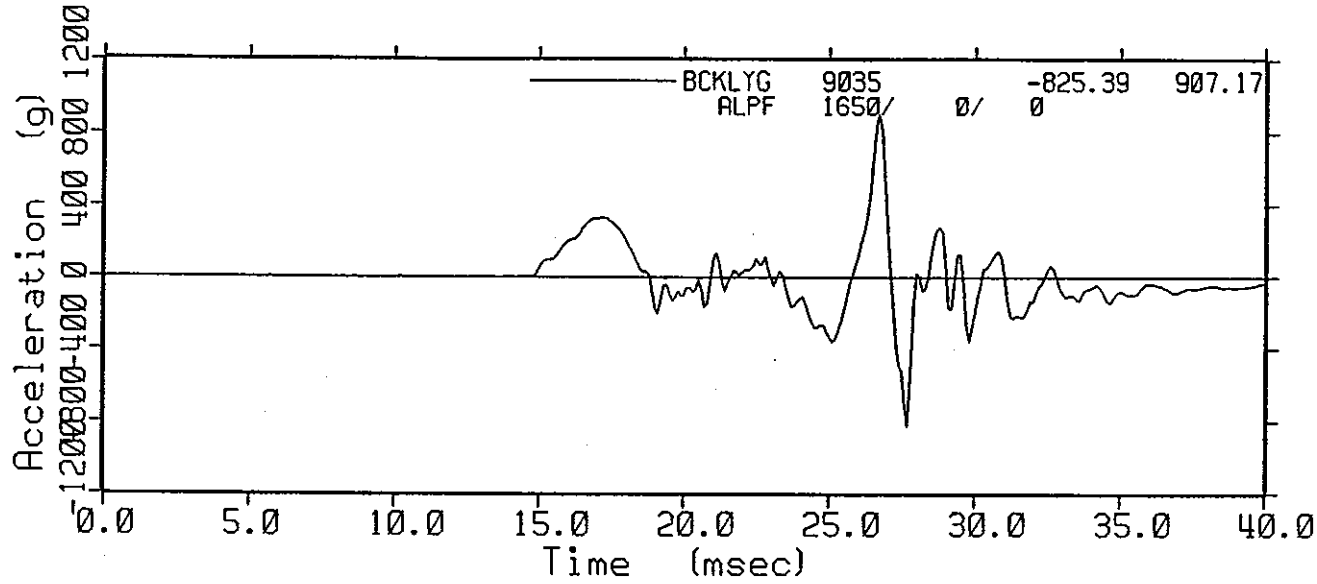

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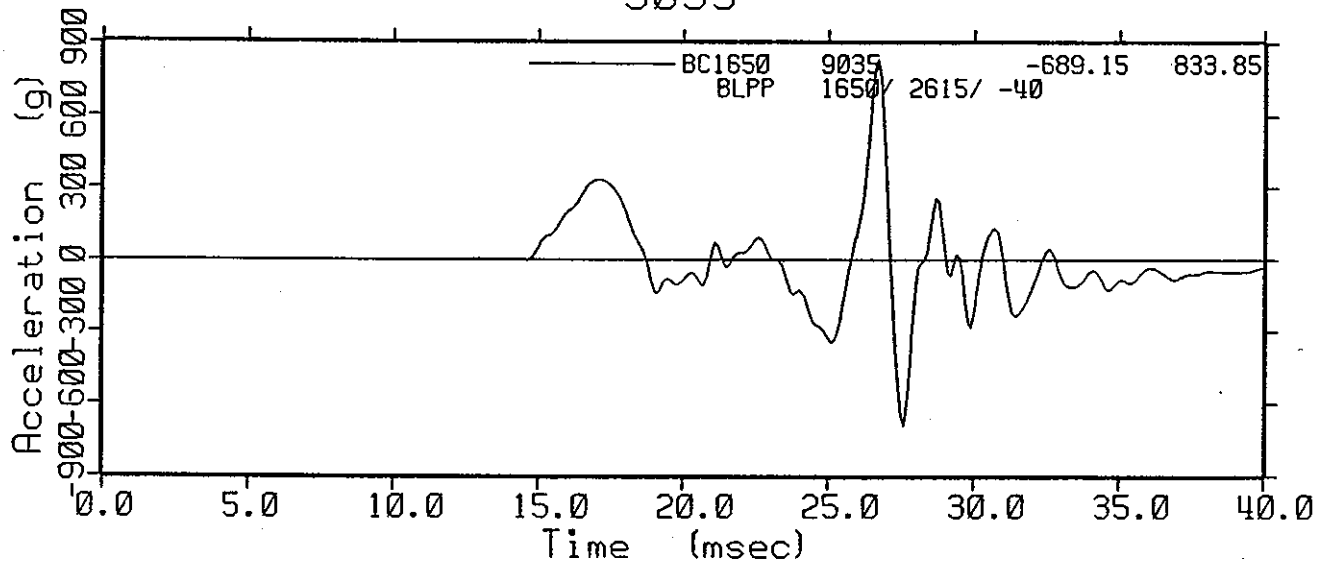

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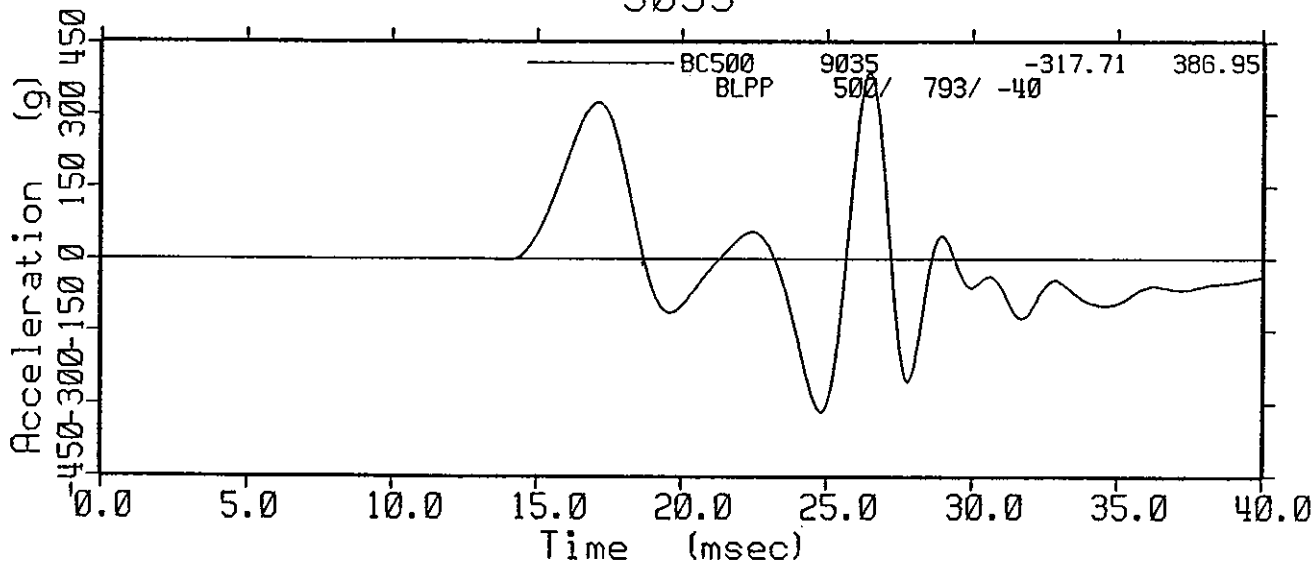

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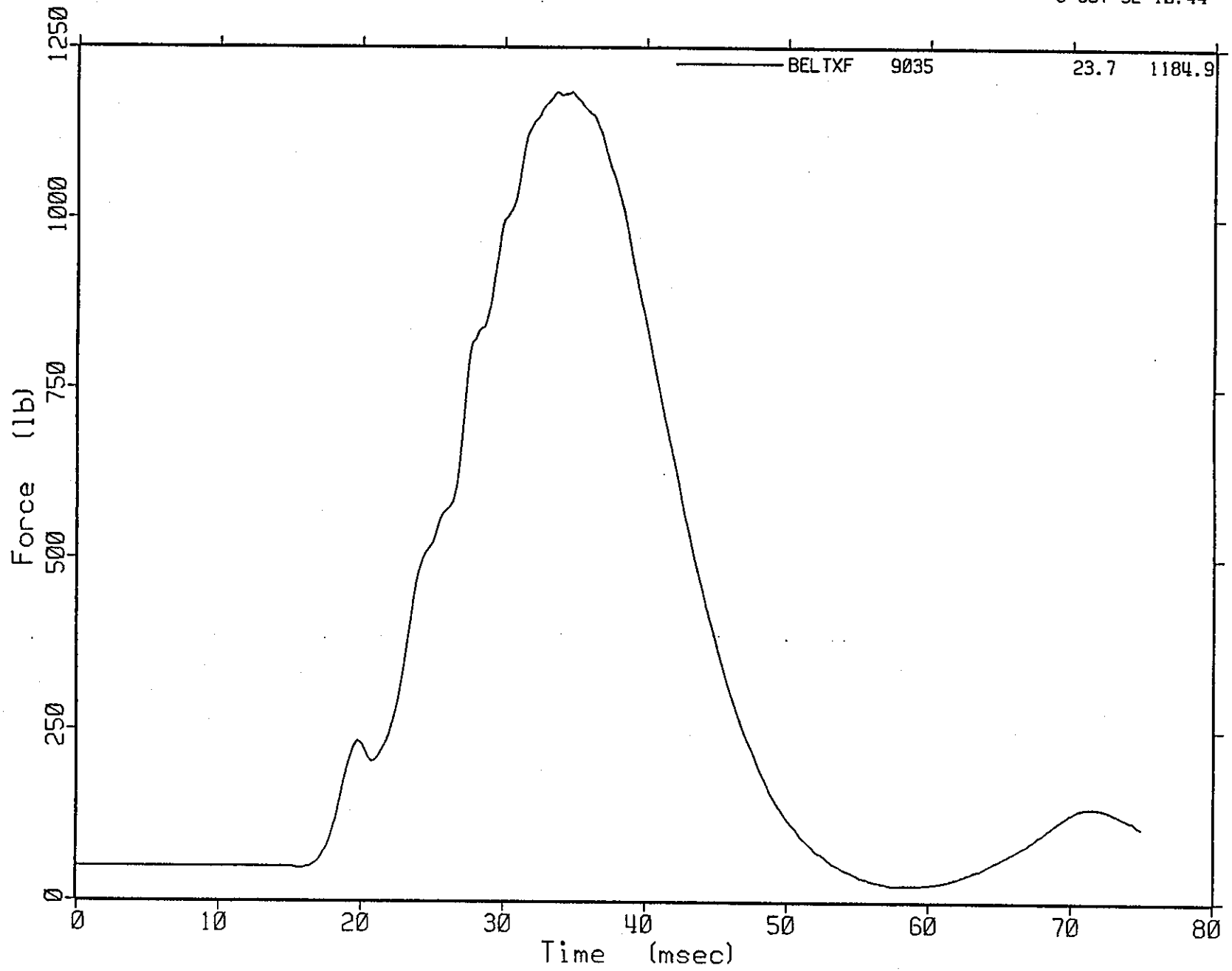

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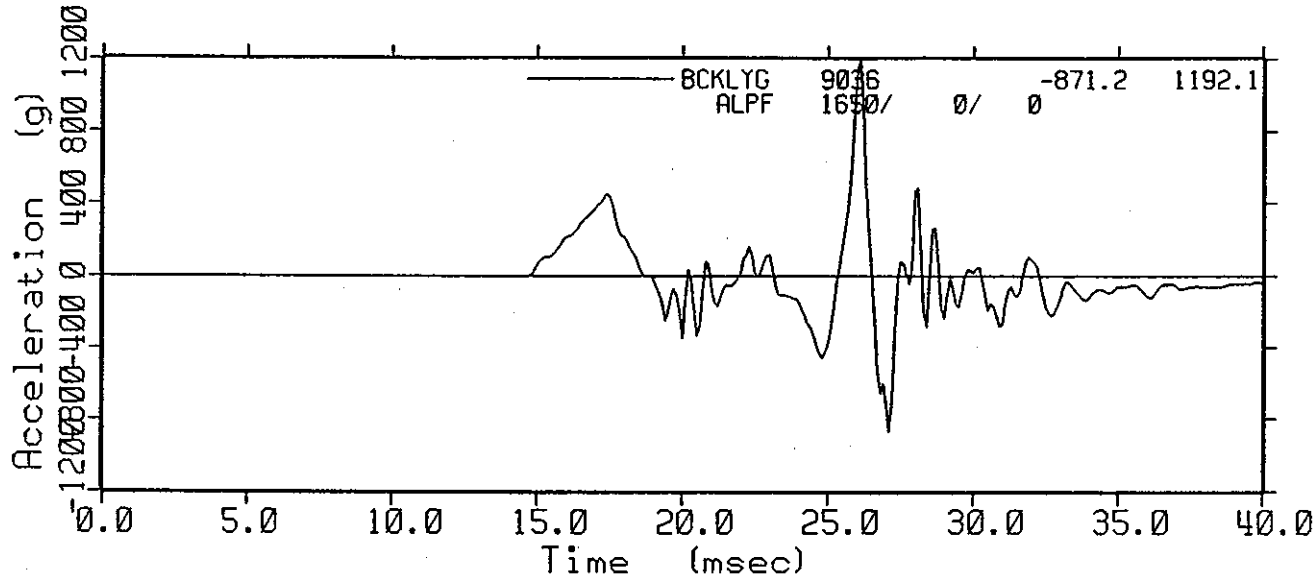

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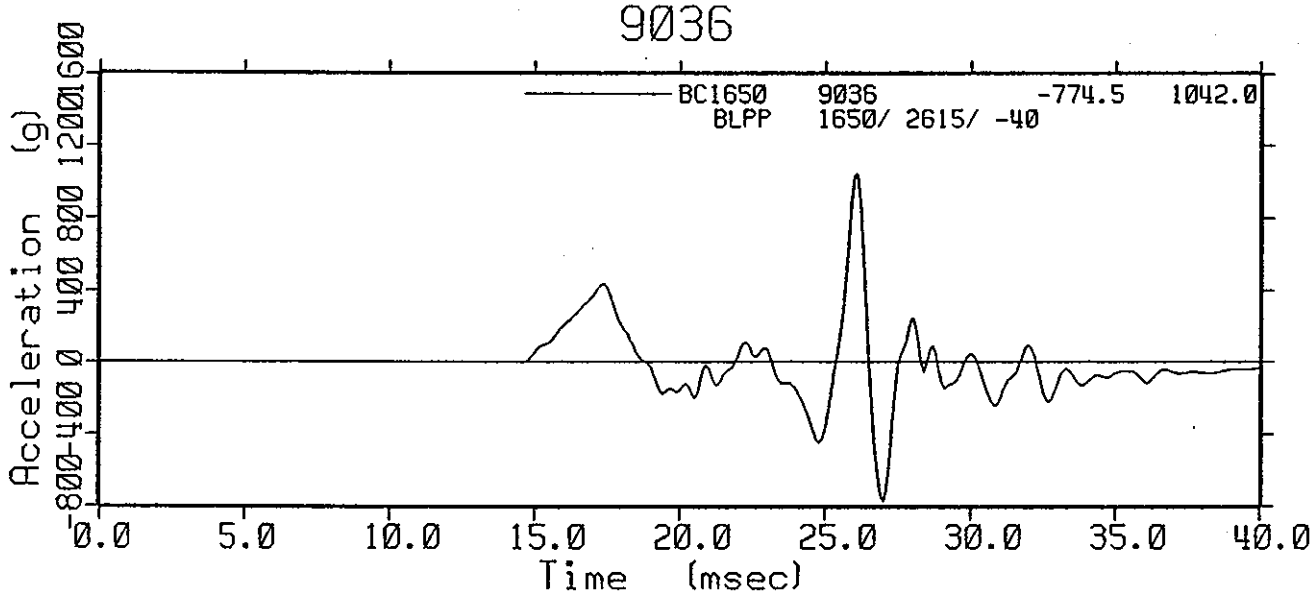

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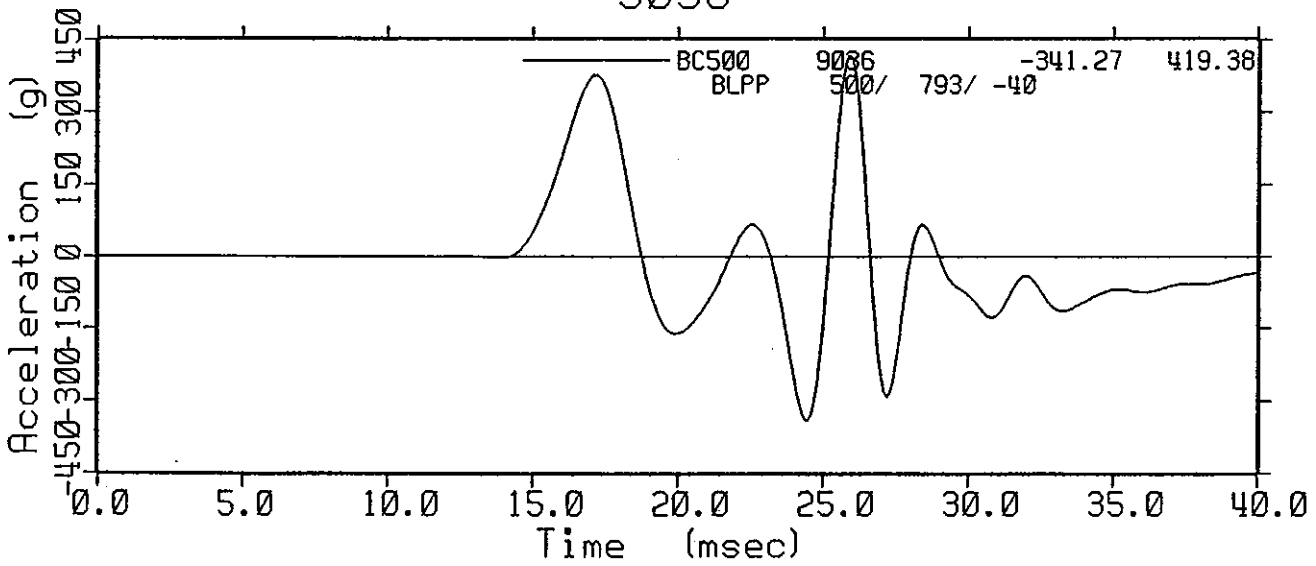

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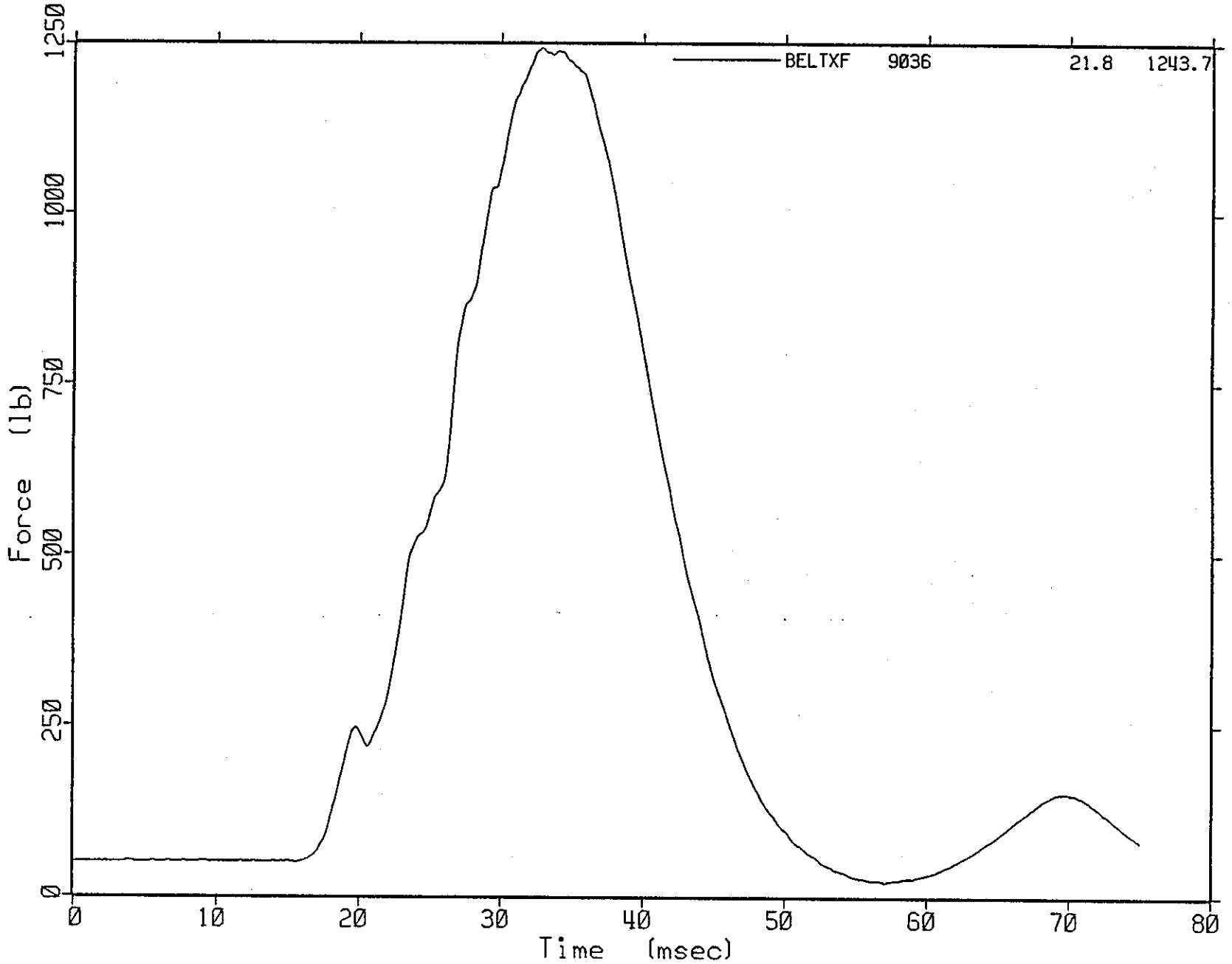

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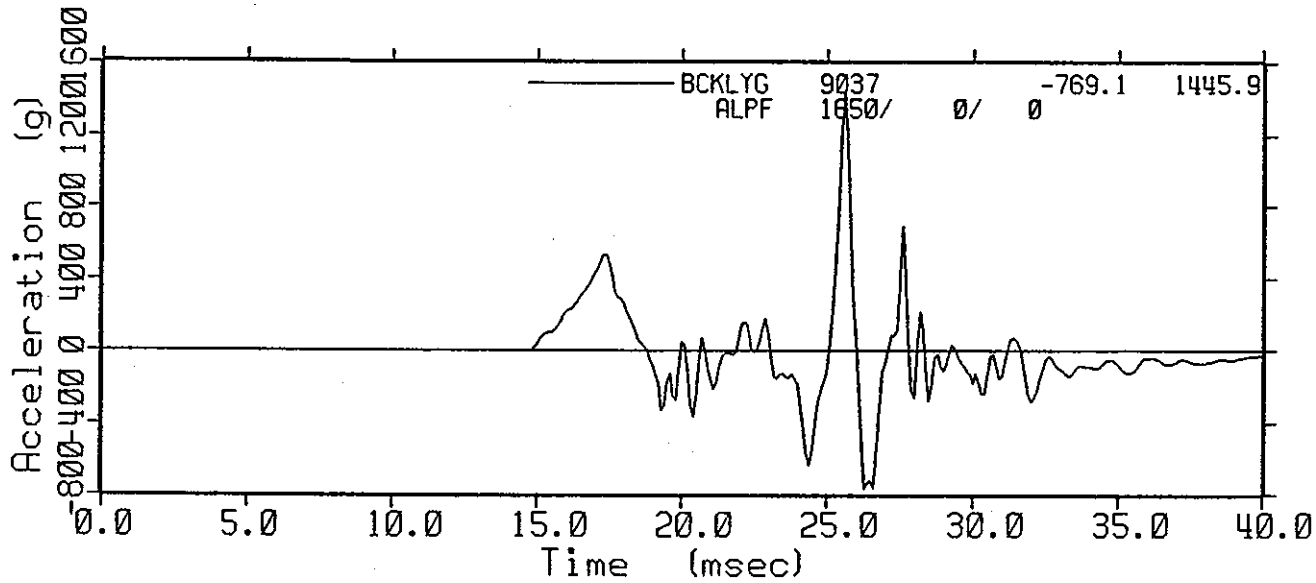

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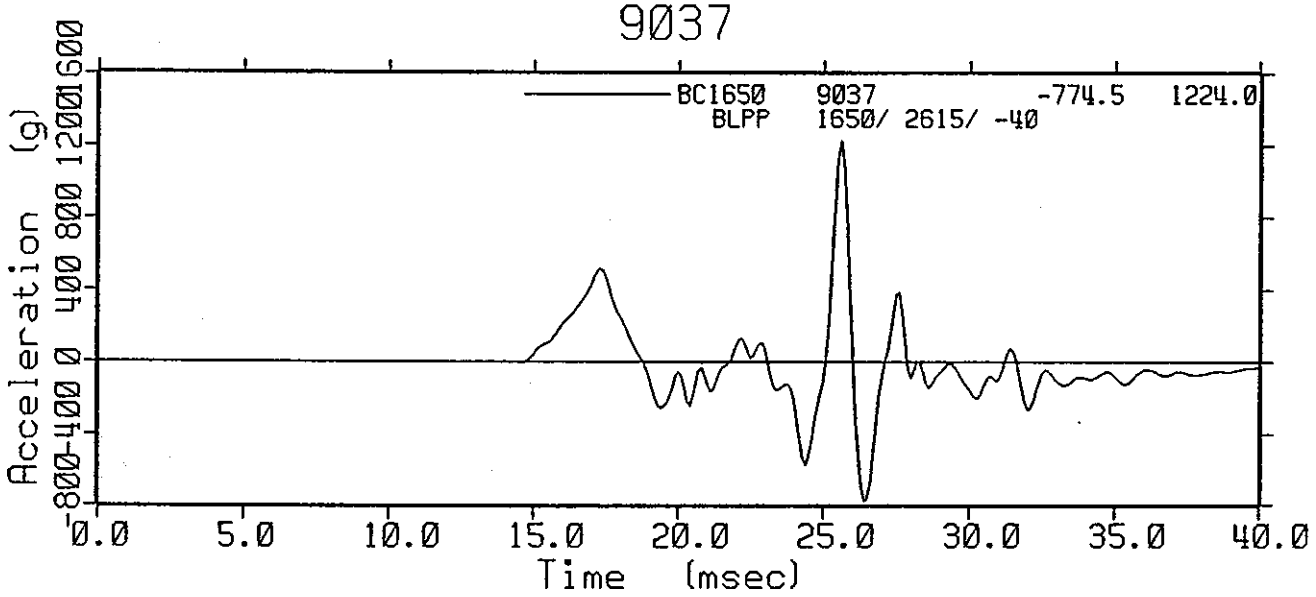

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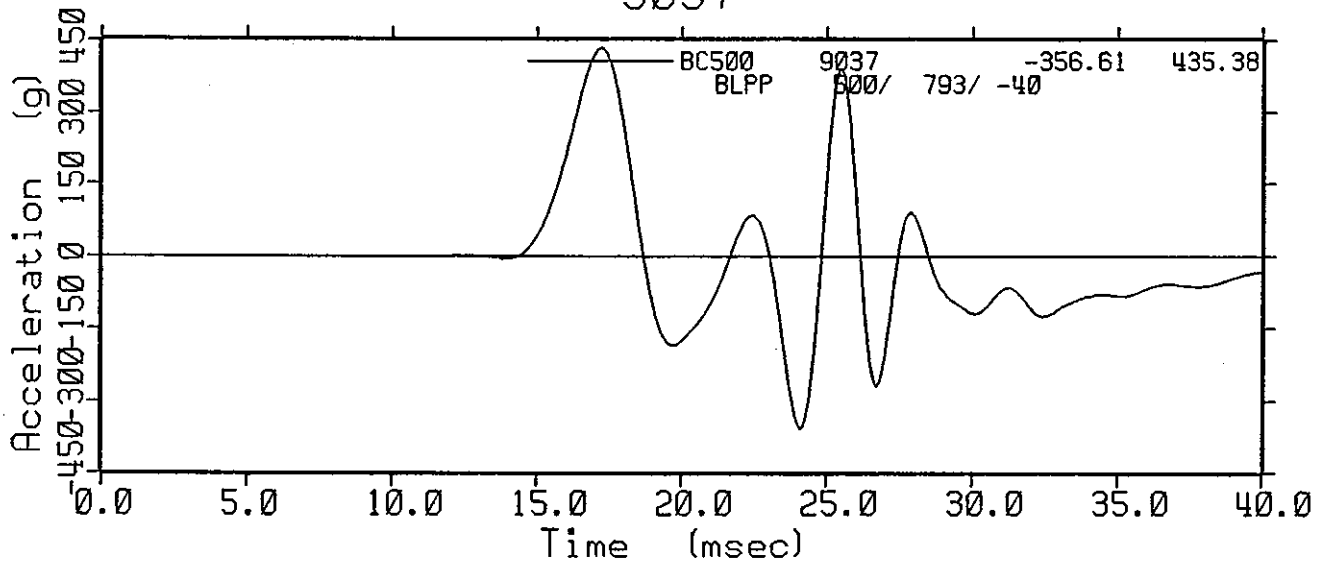

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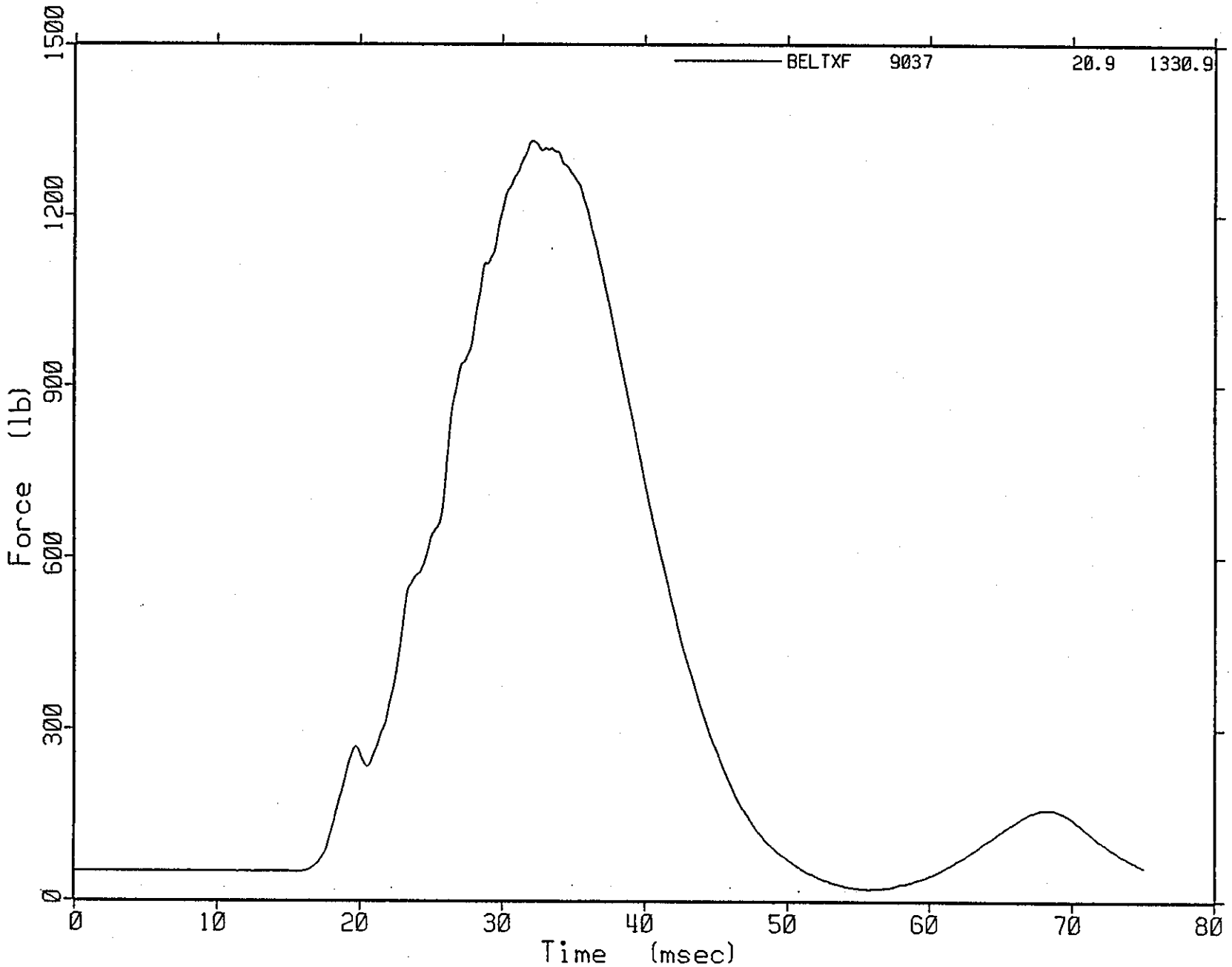

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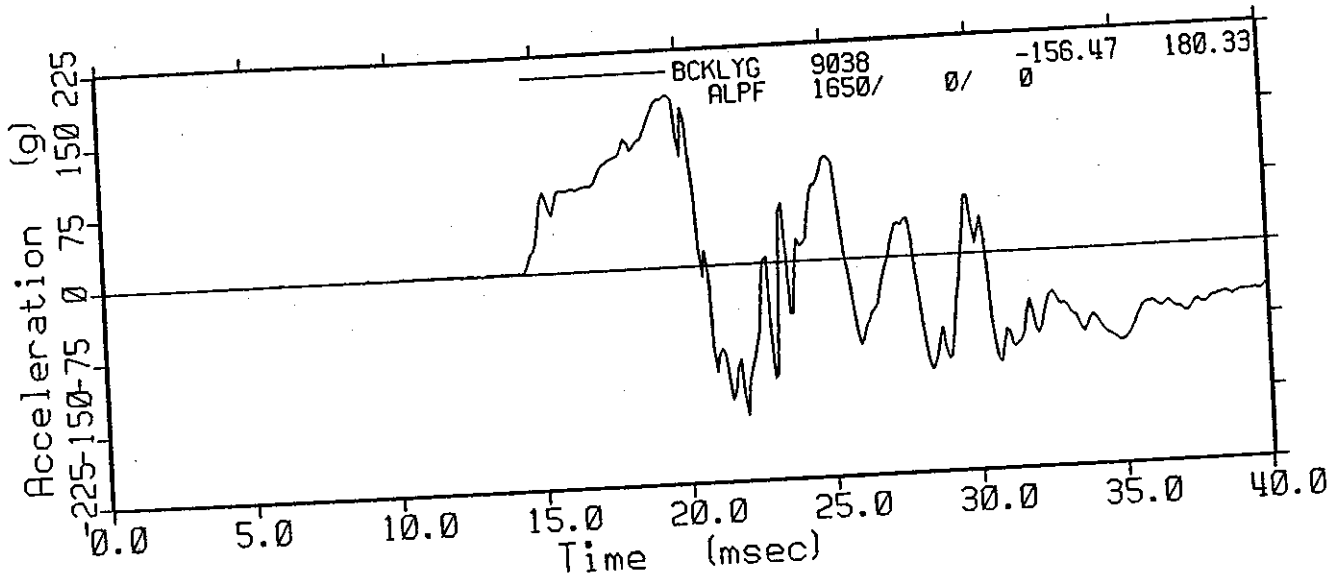

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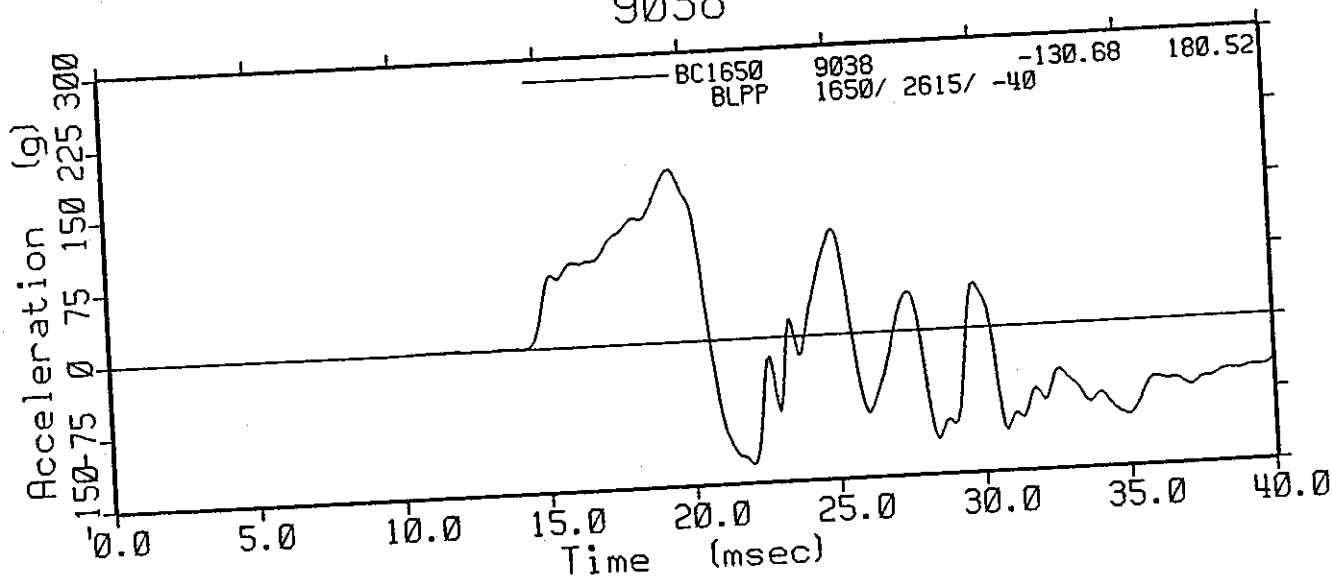

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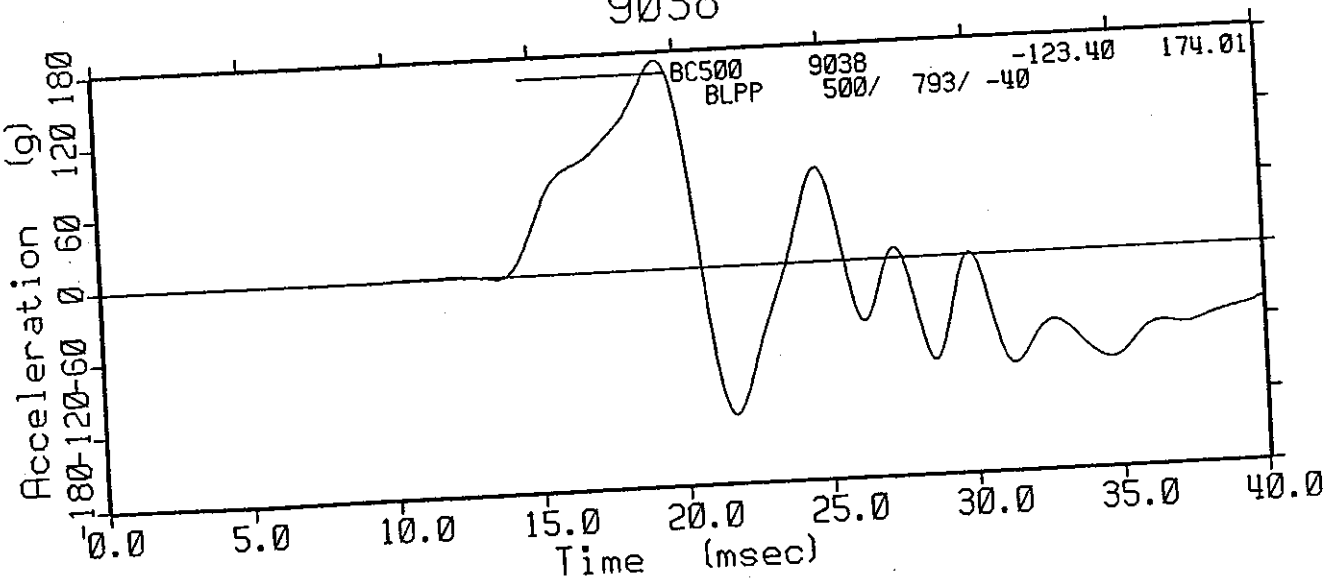

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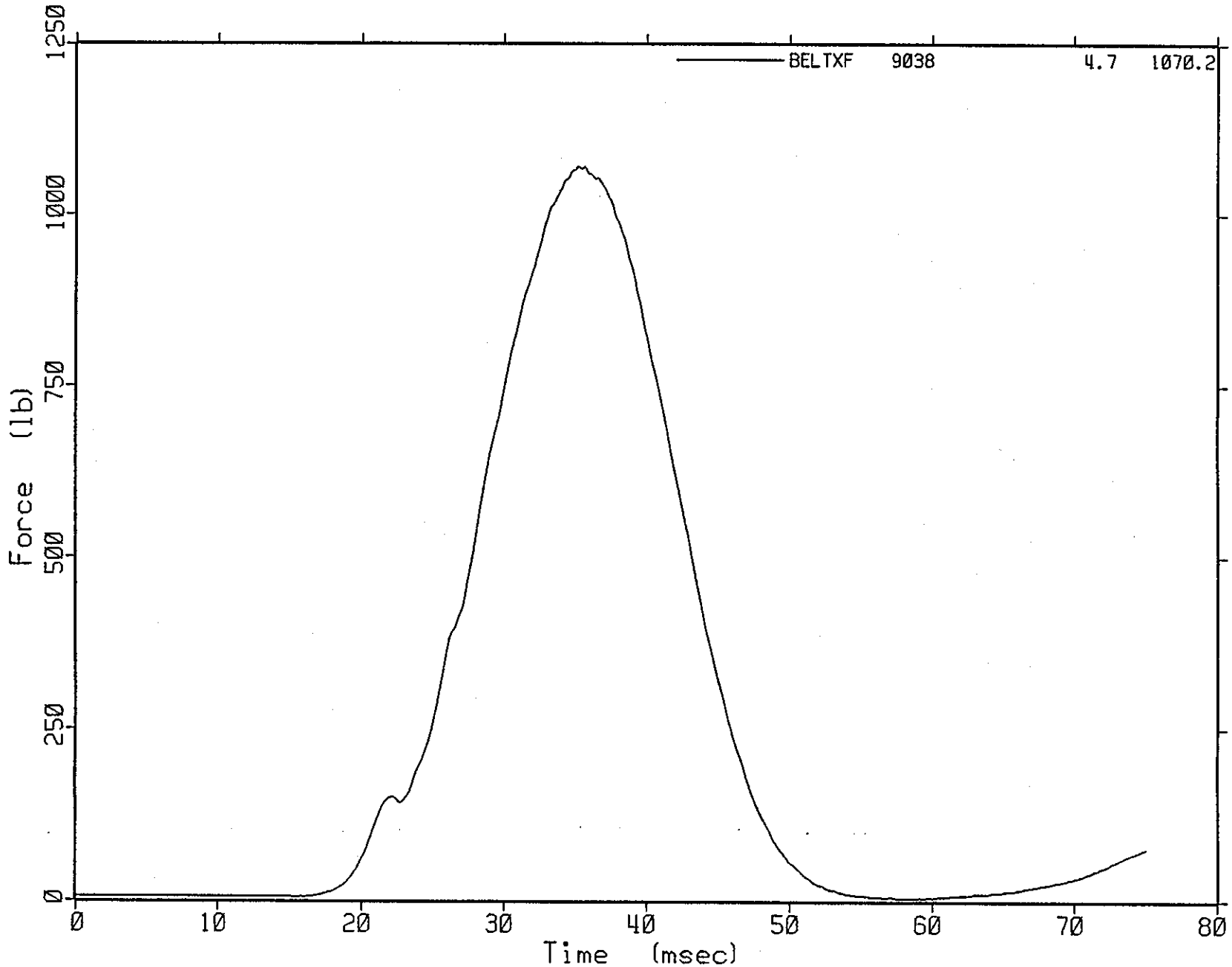

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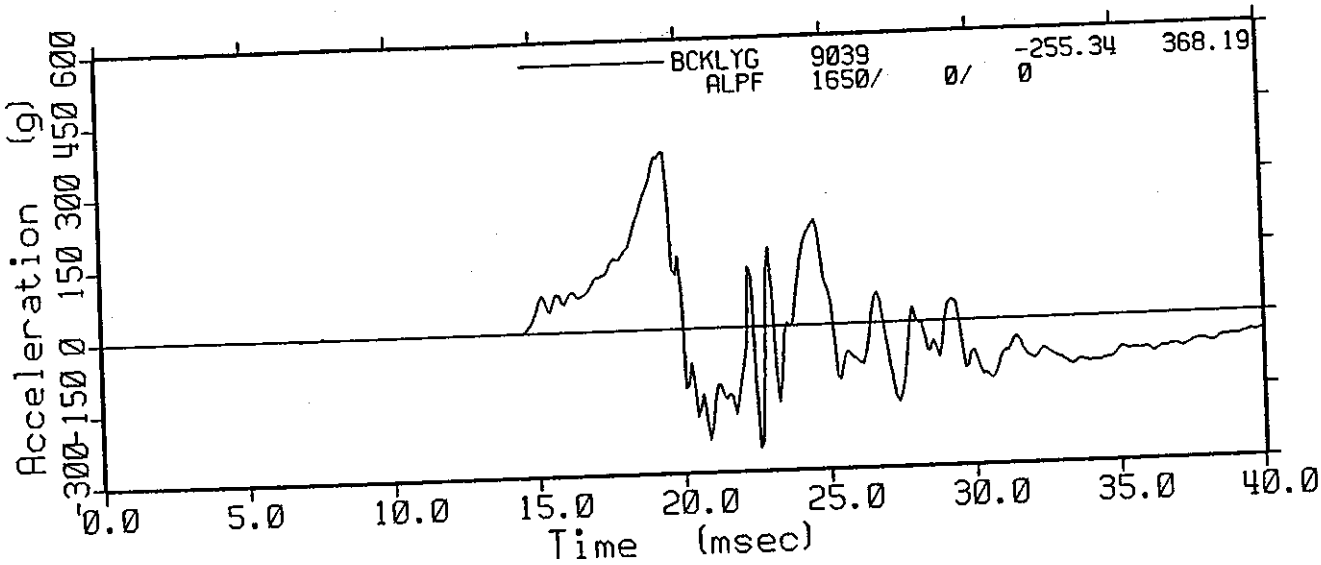

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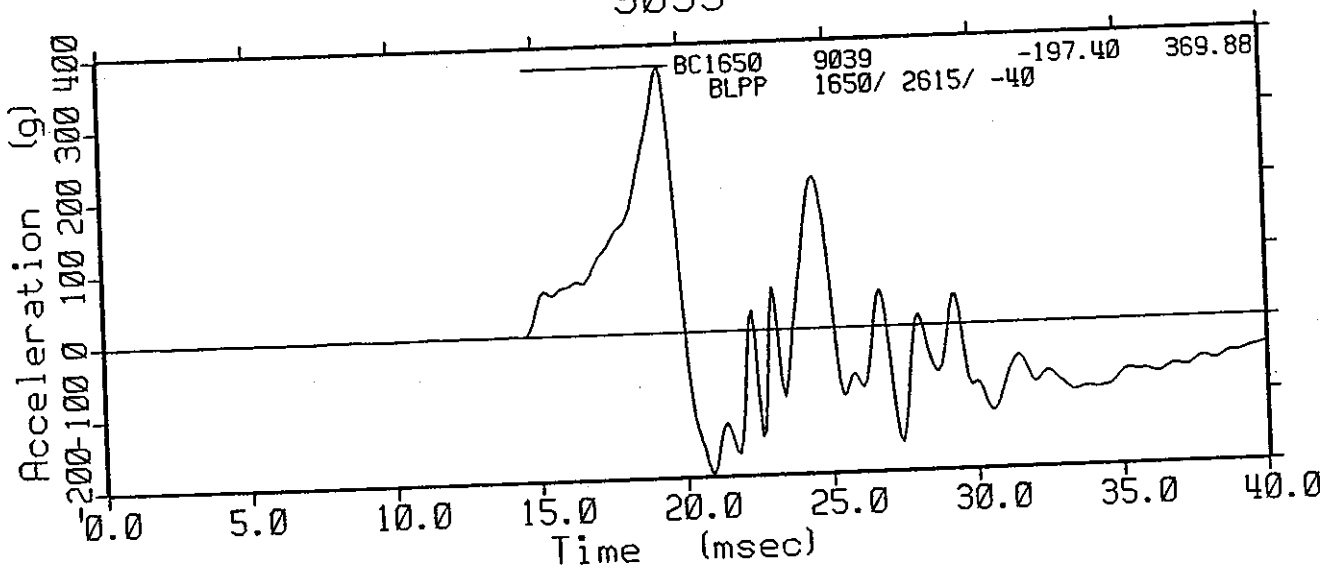

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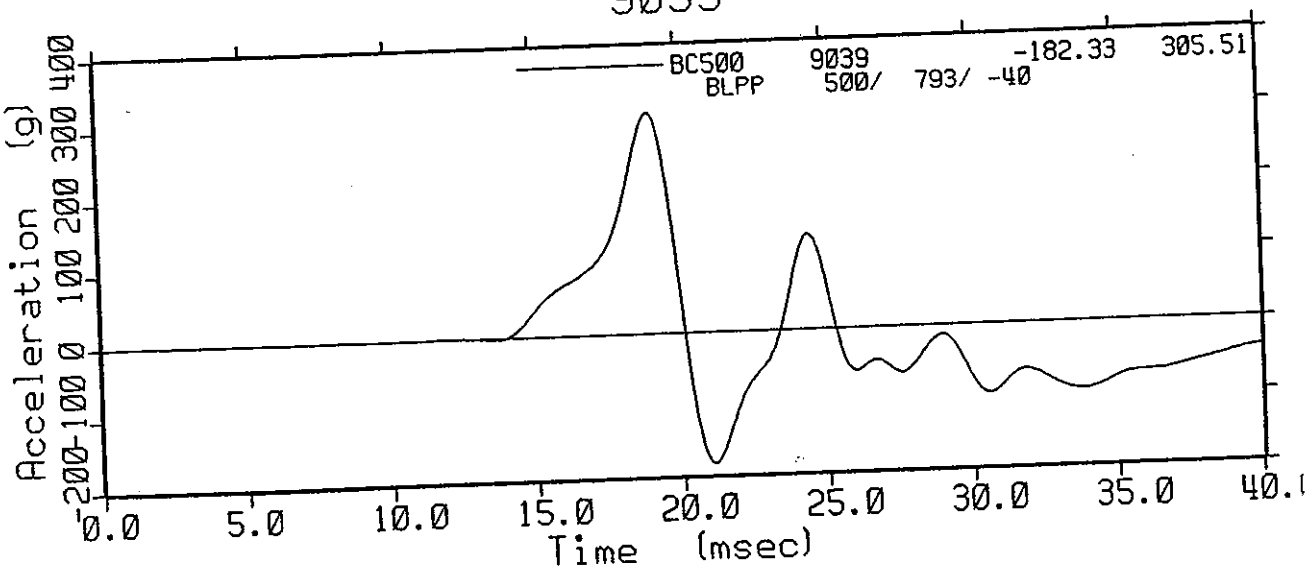

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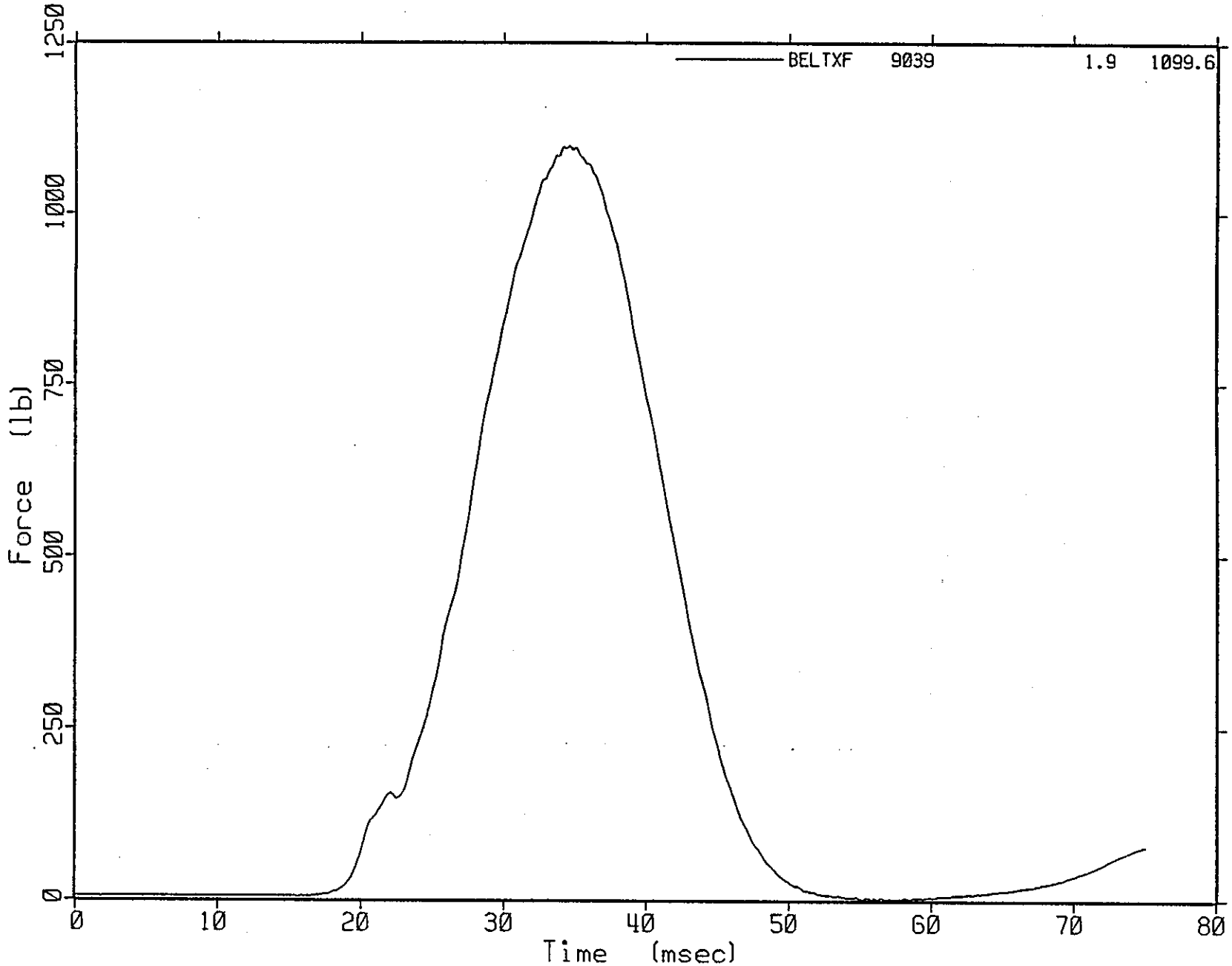

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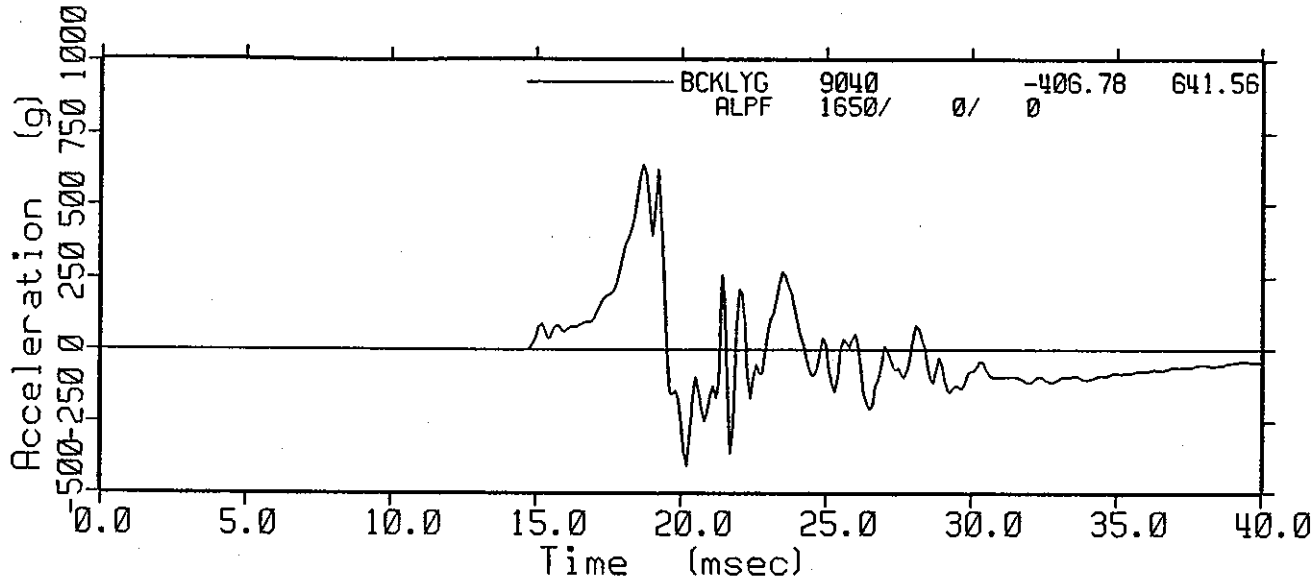

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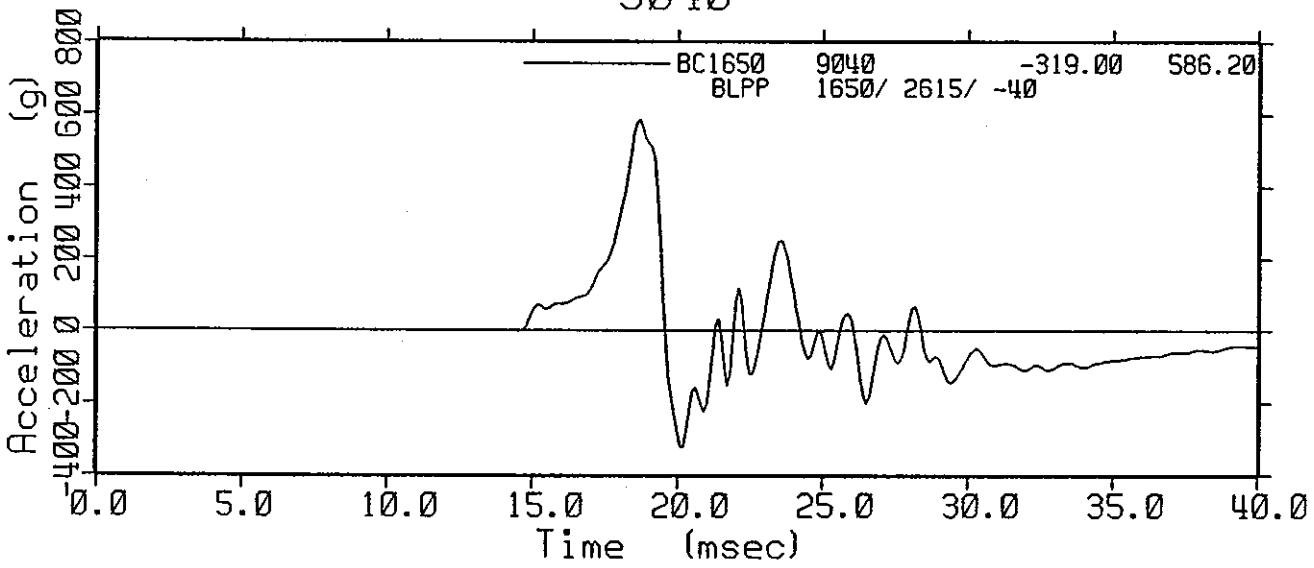

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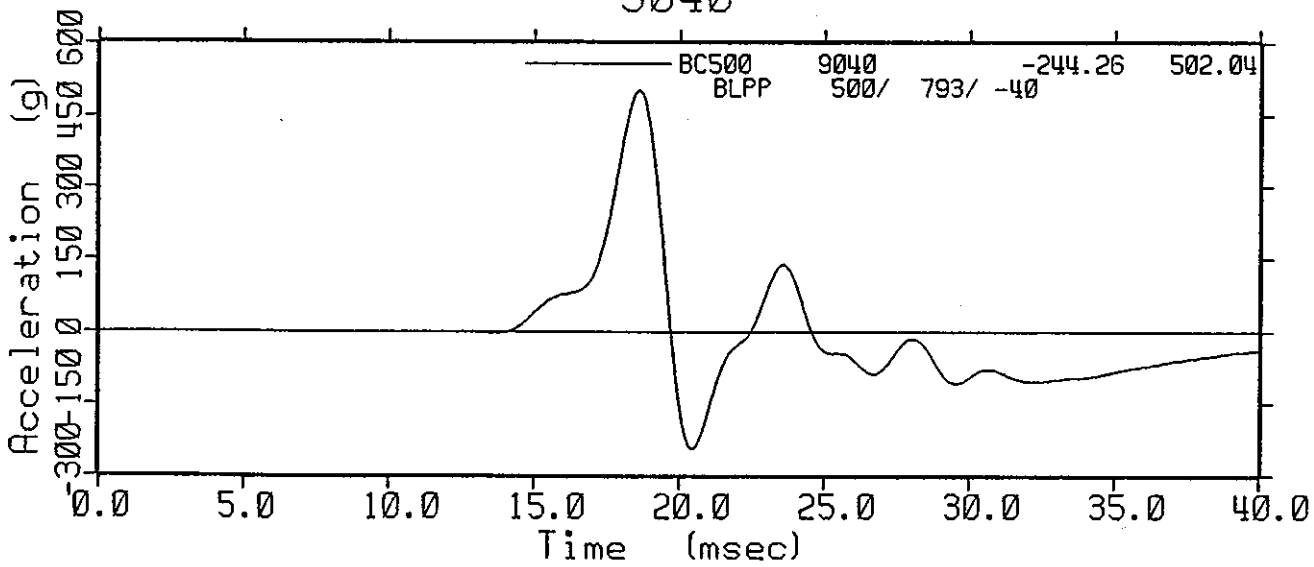

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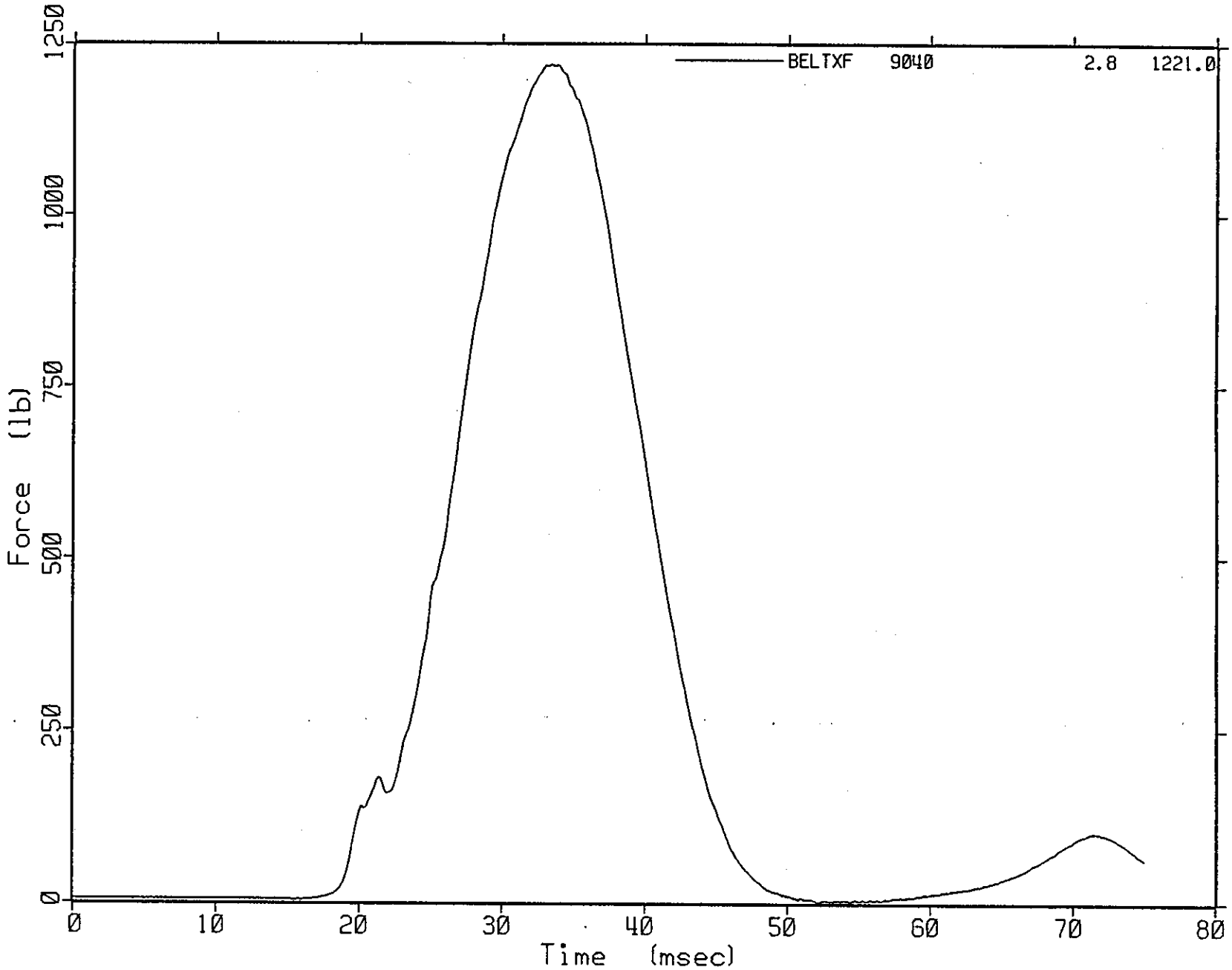

TEST 9040 - FORCE

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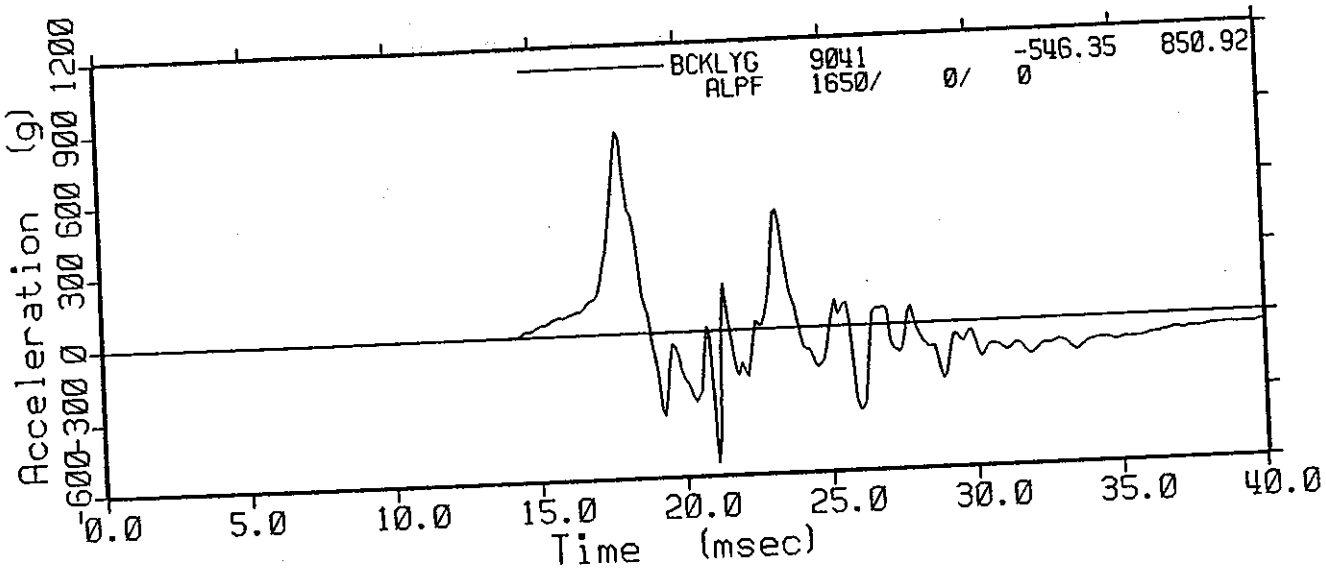

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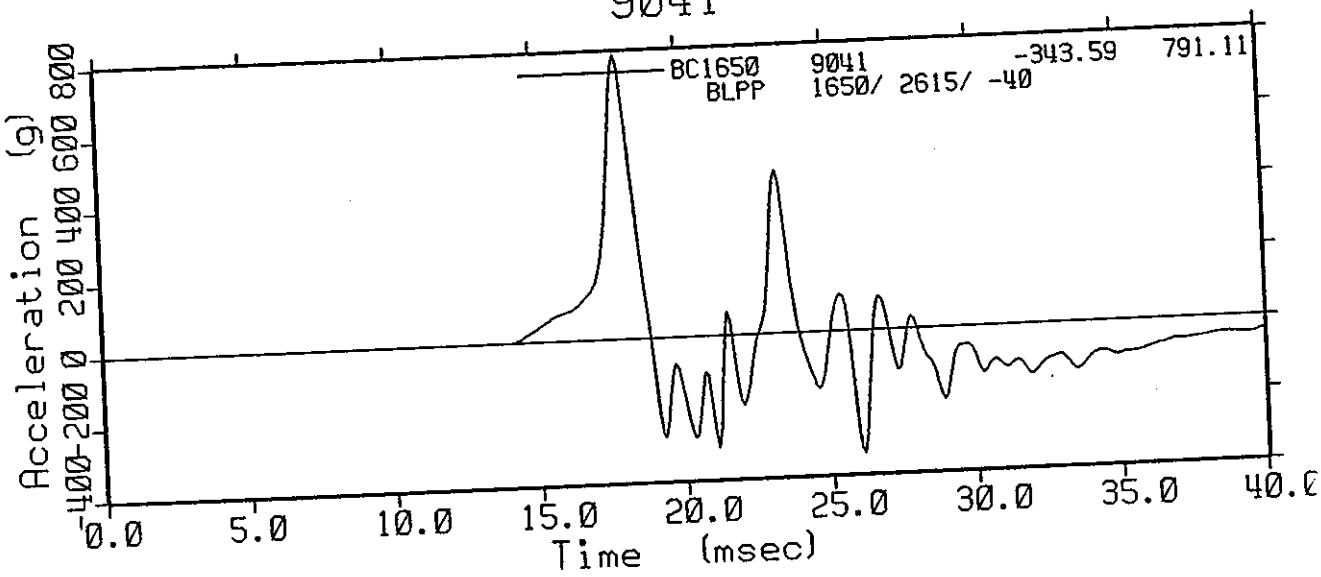

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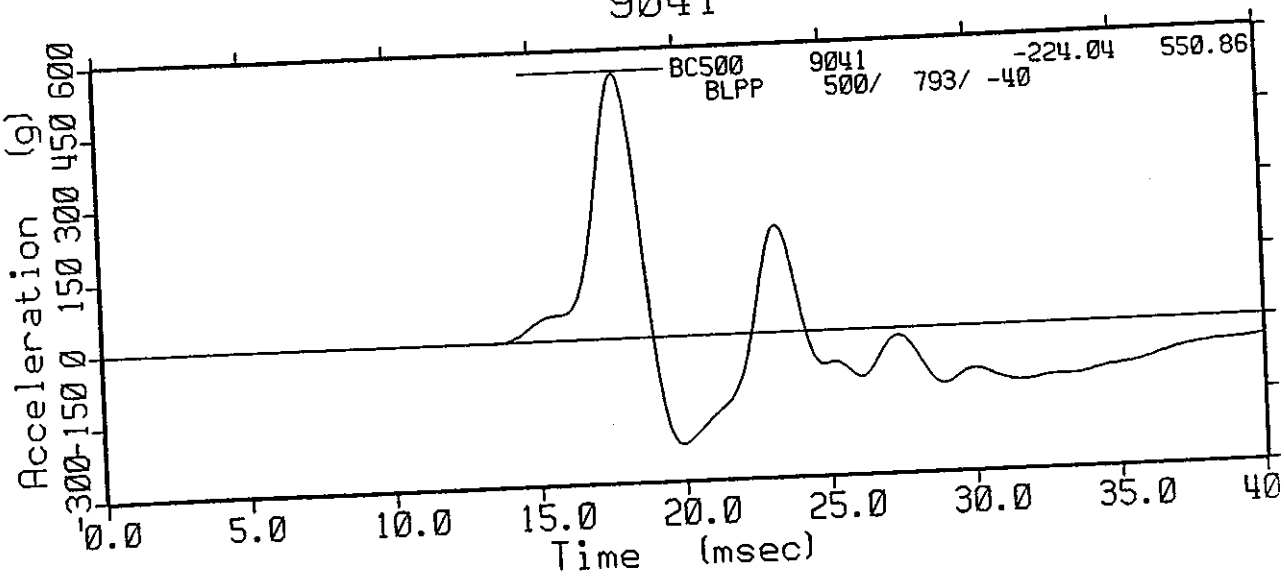

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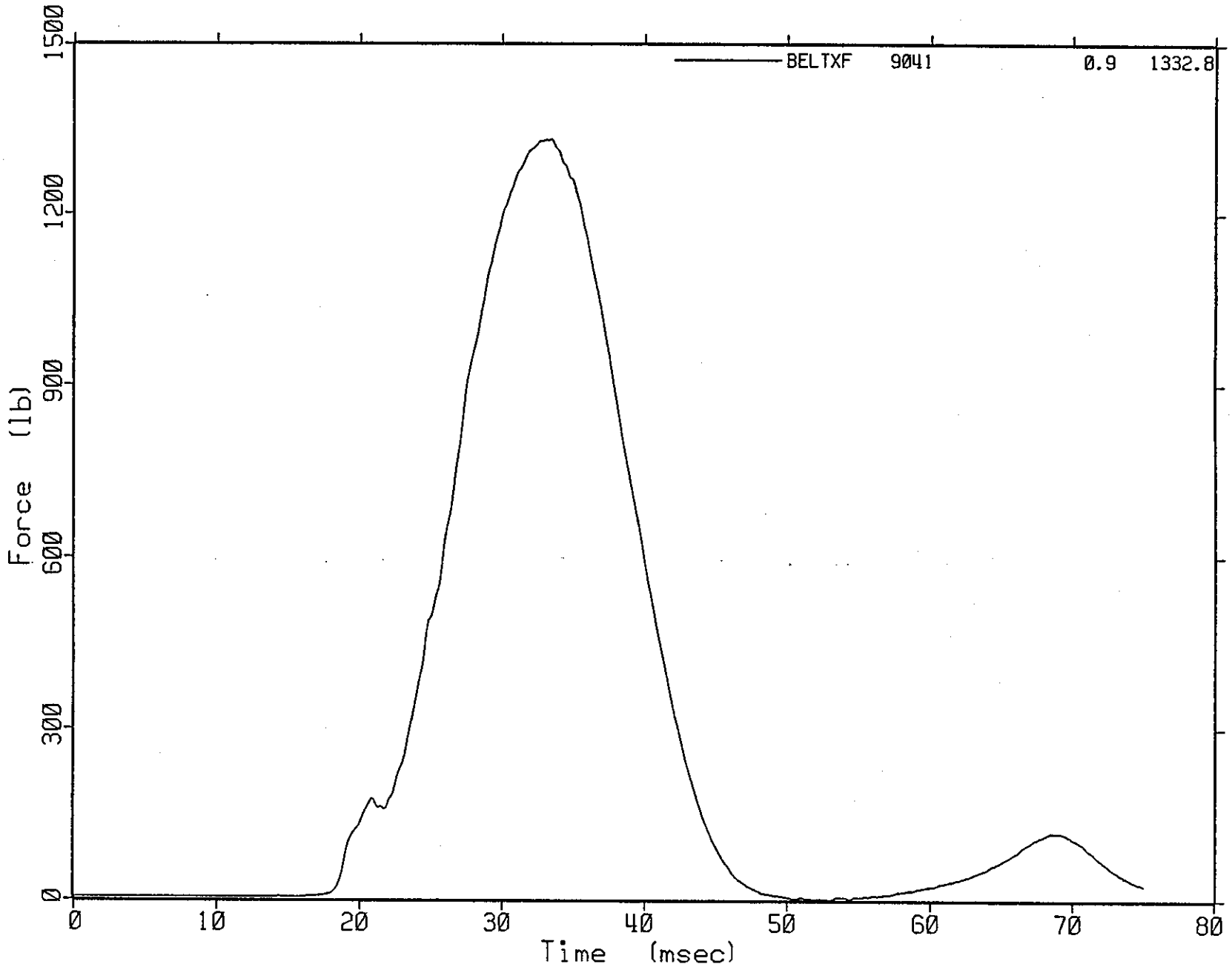

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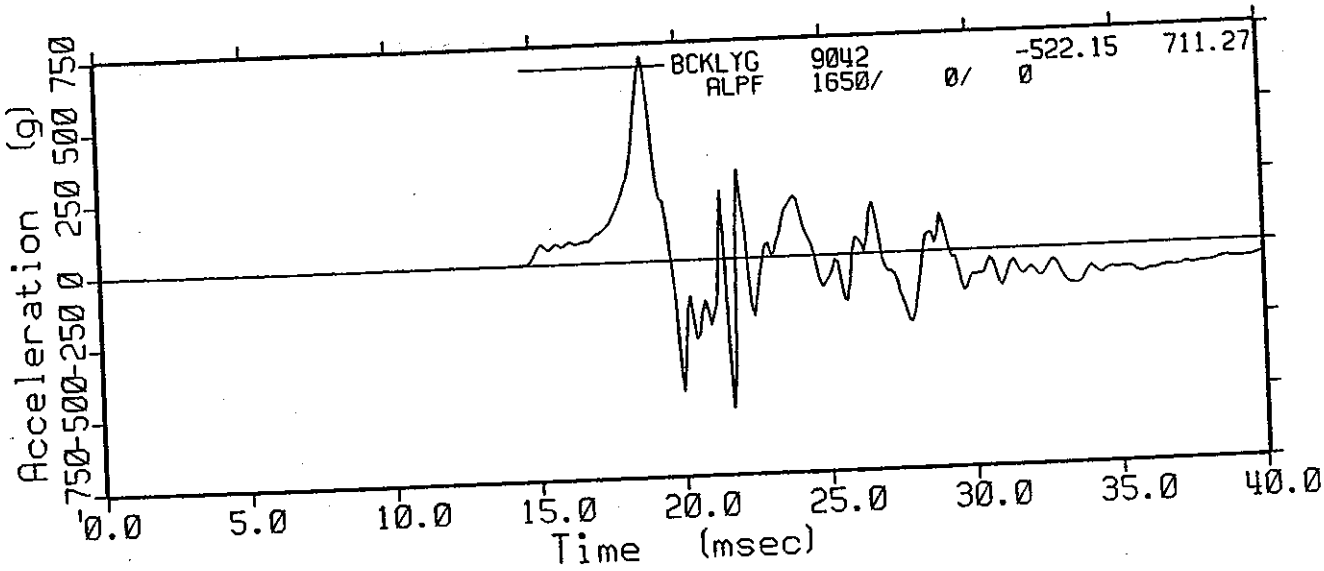

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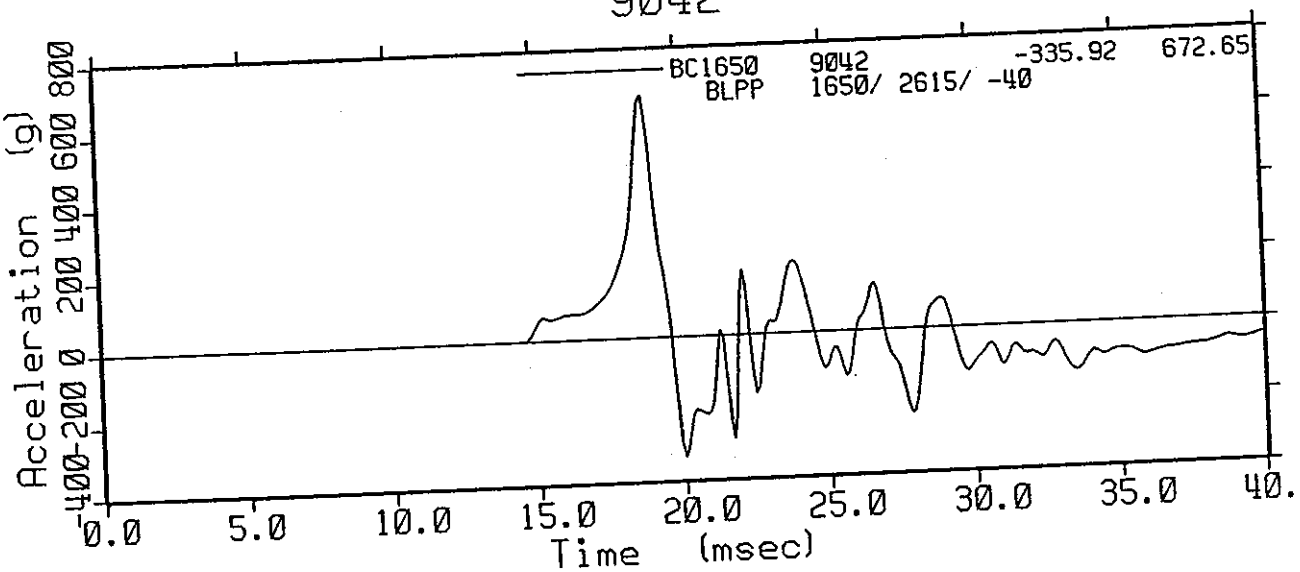

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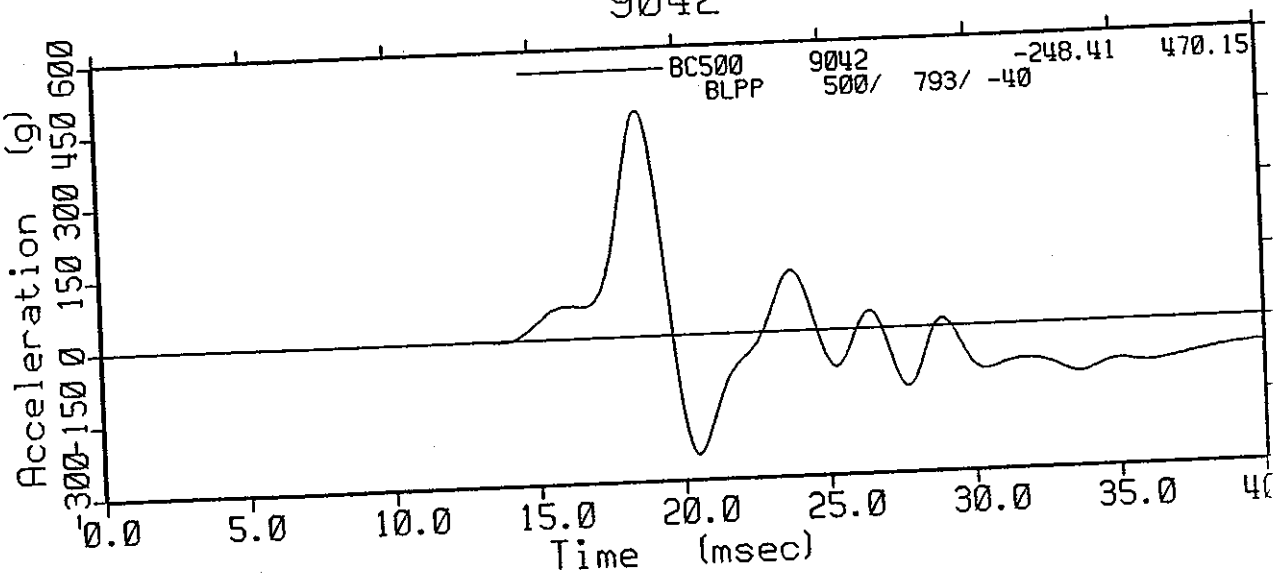

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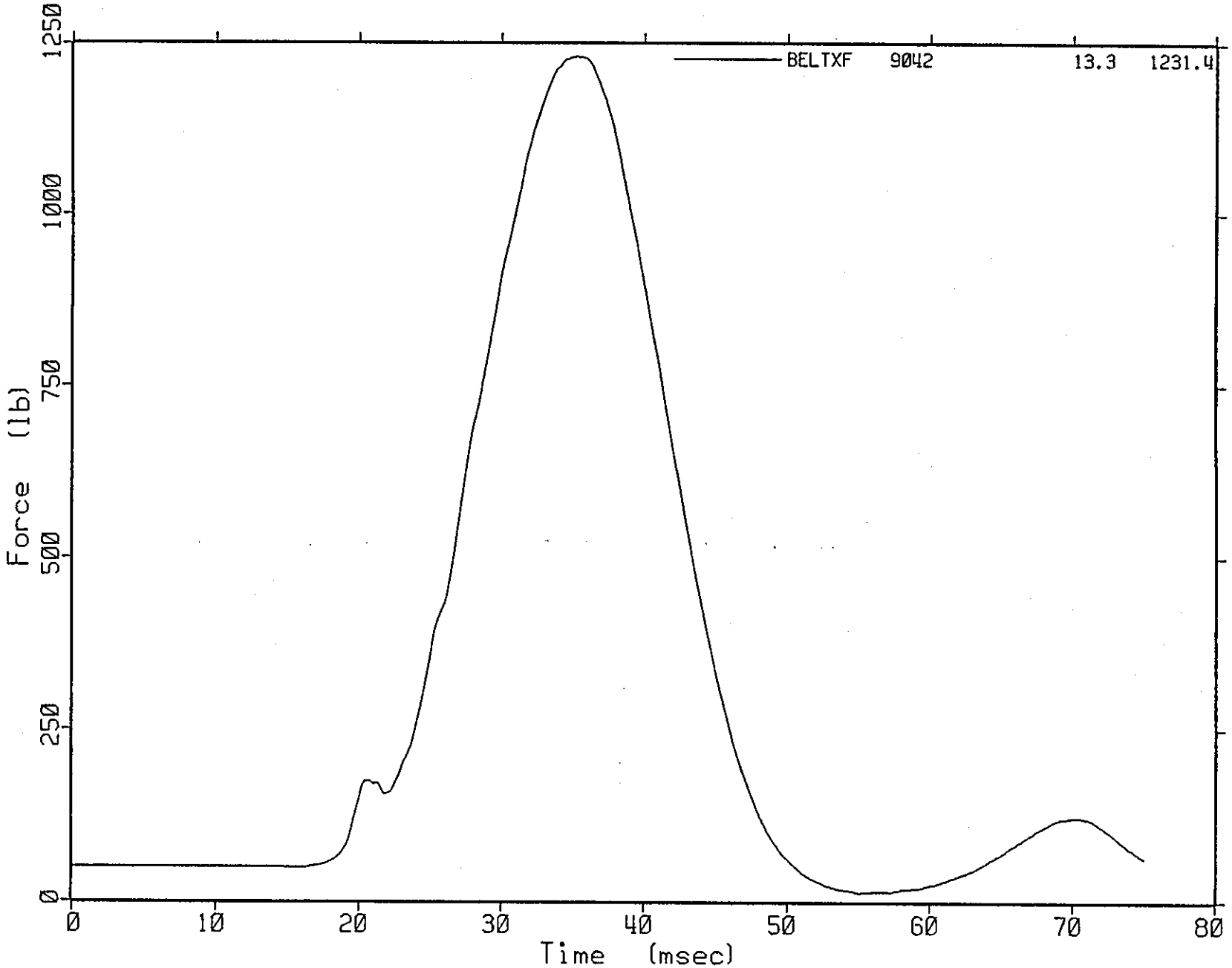

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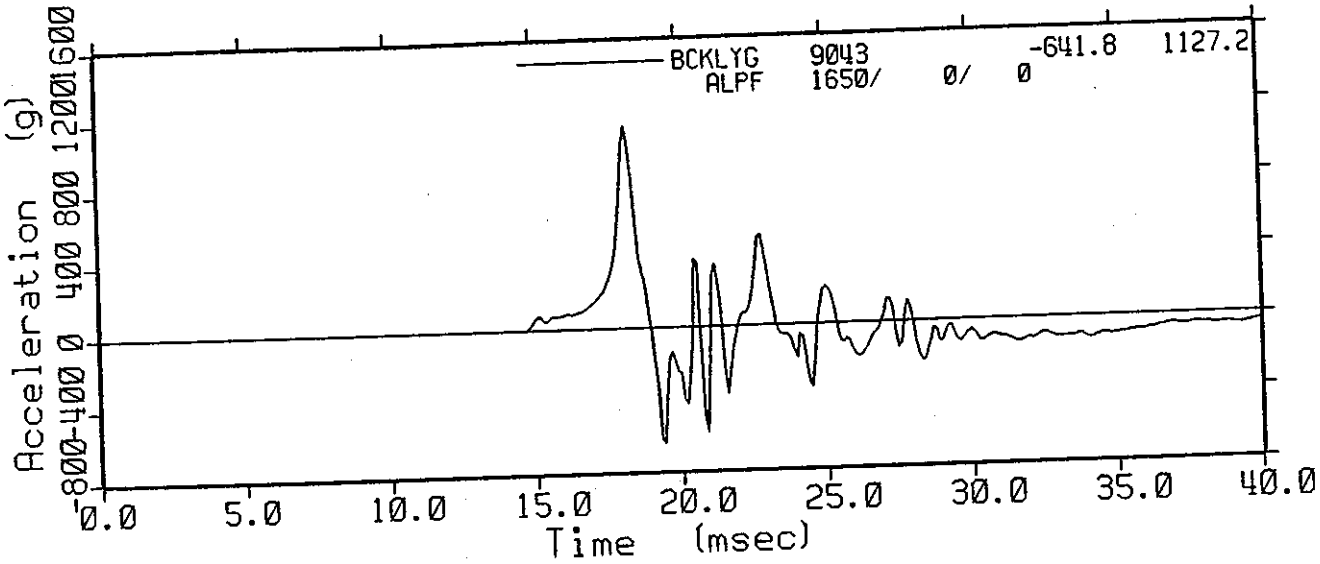

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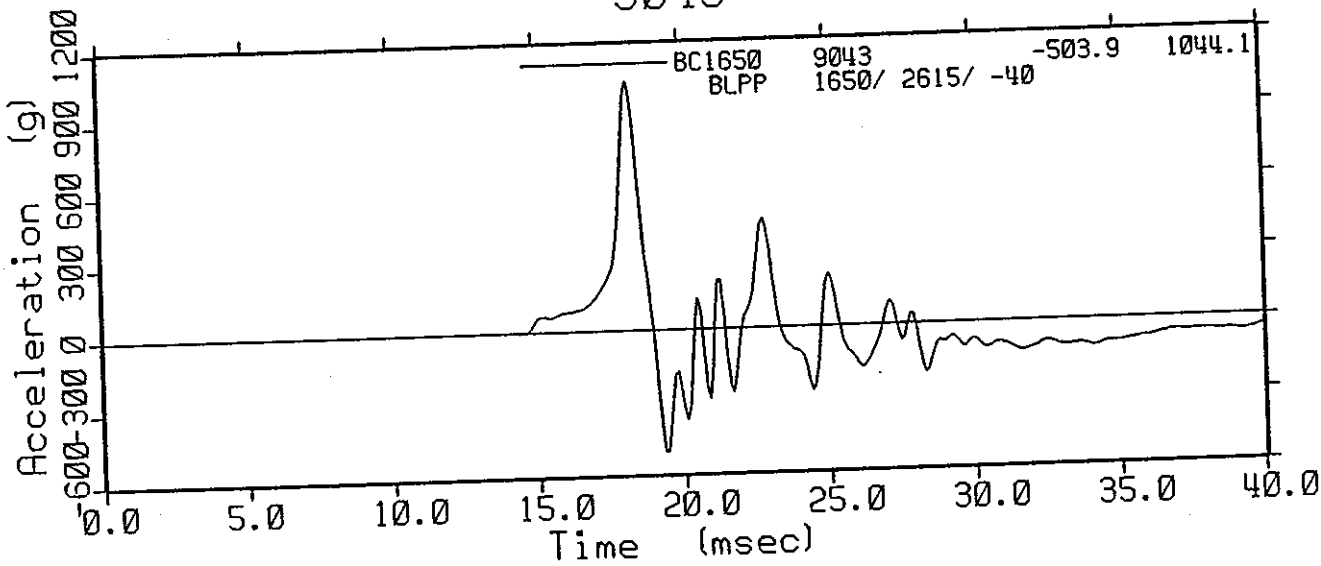

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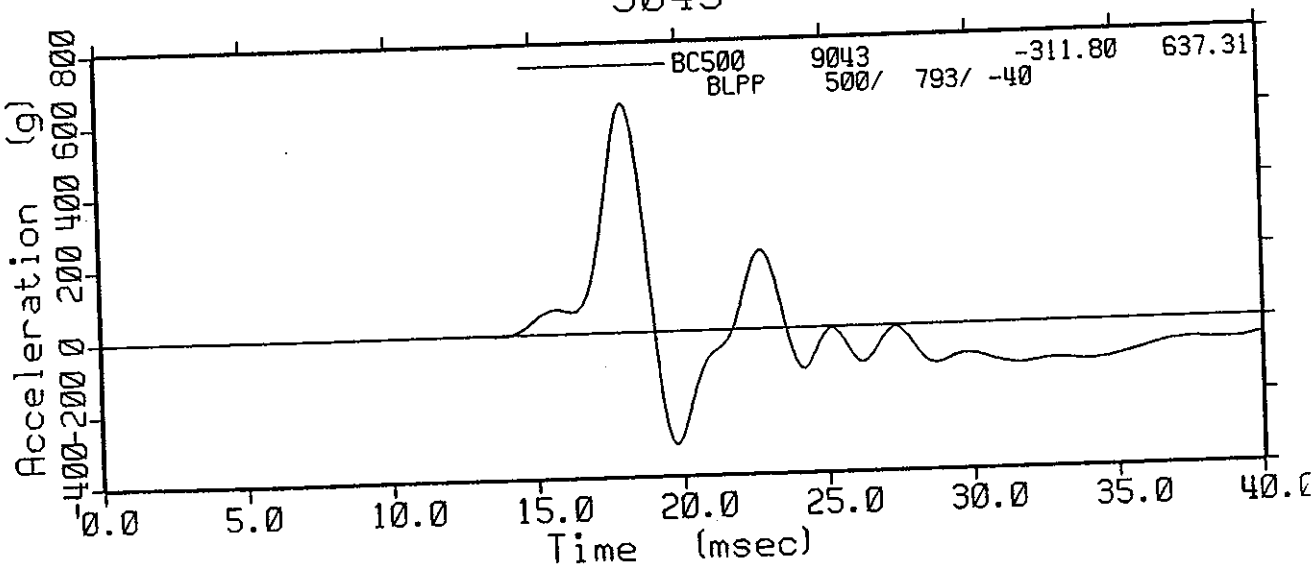

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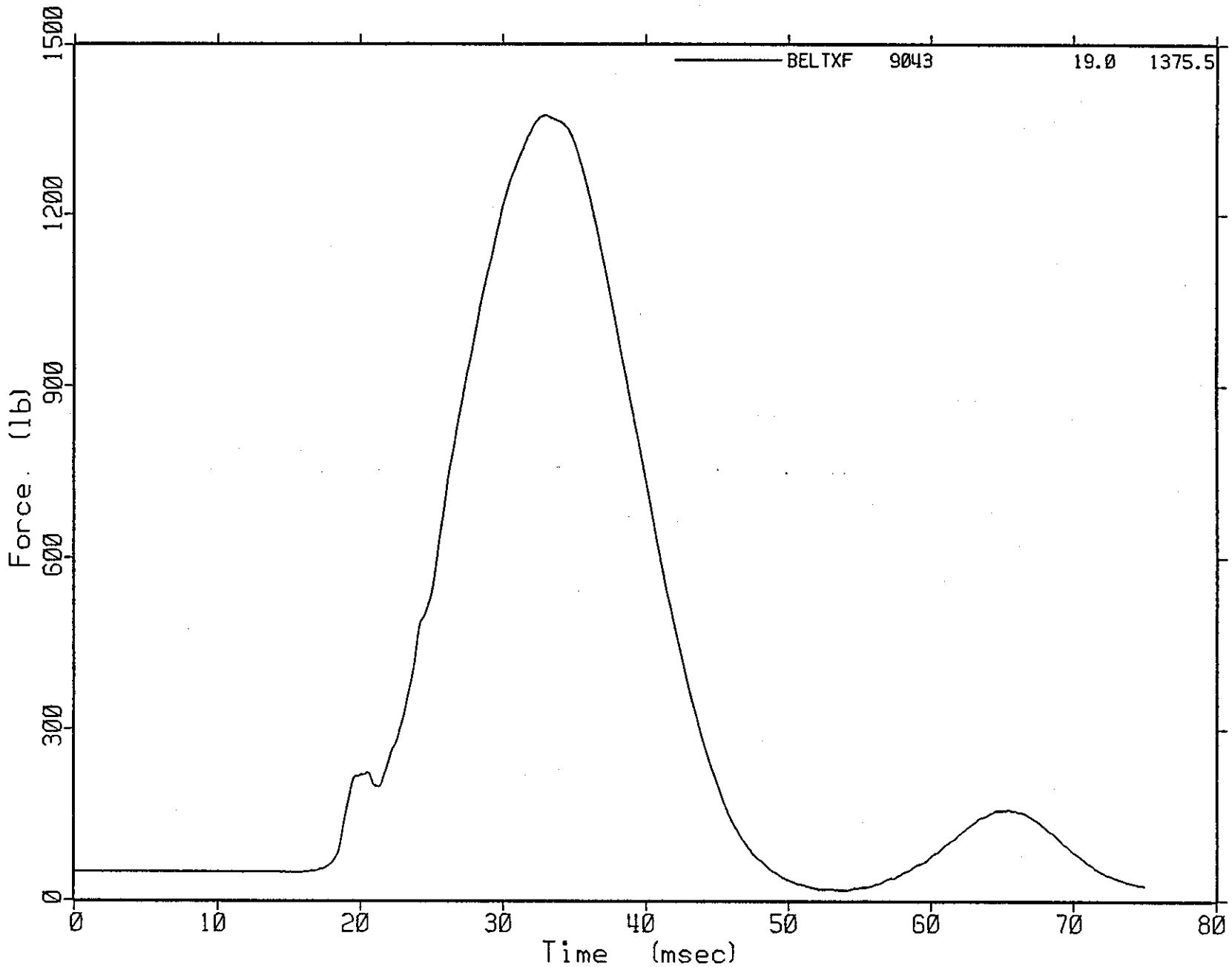

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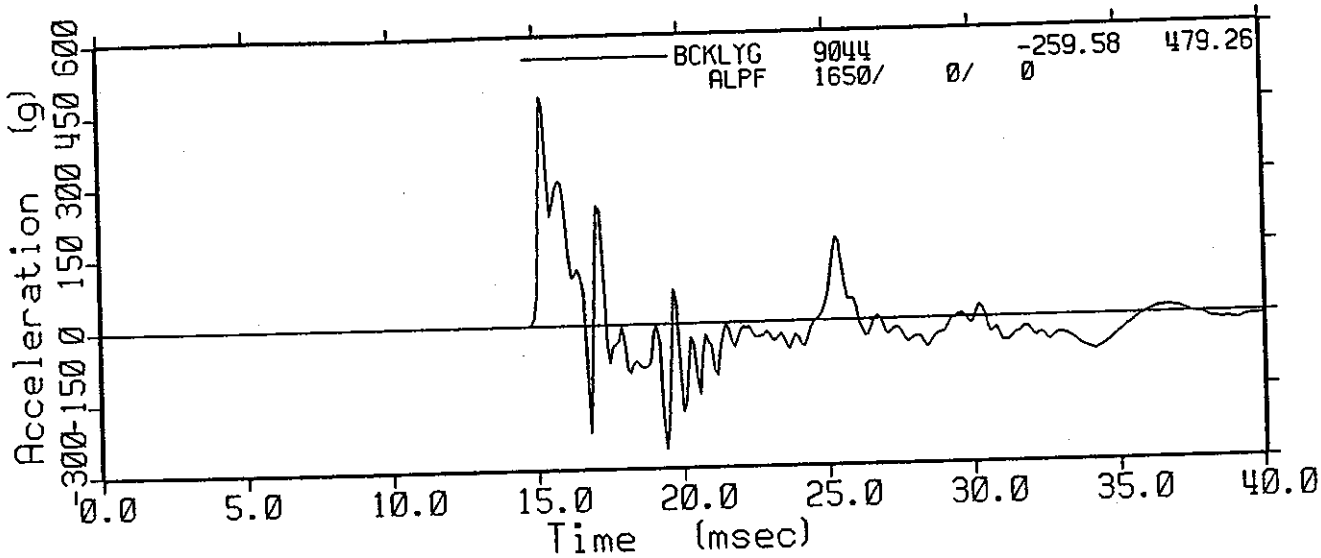

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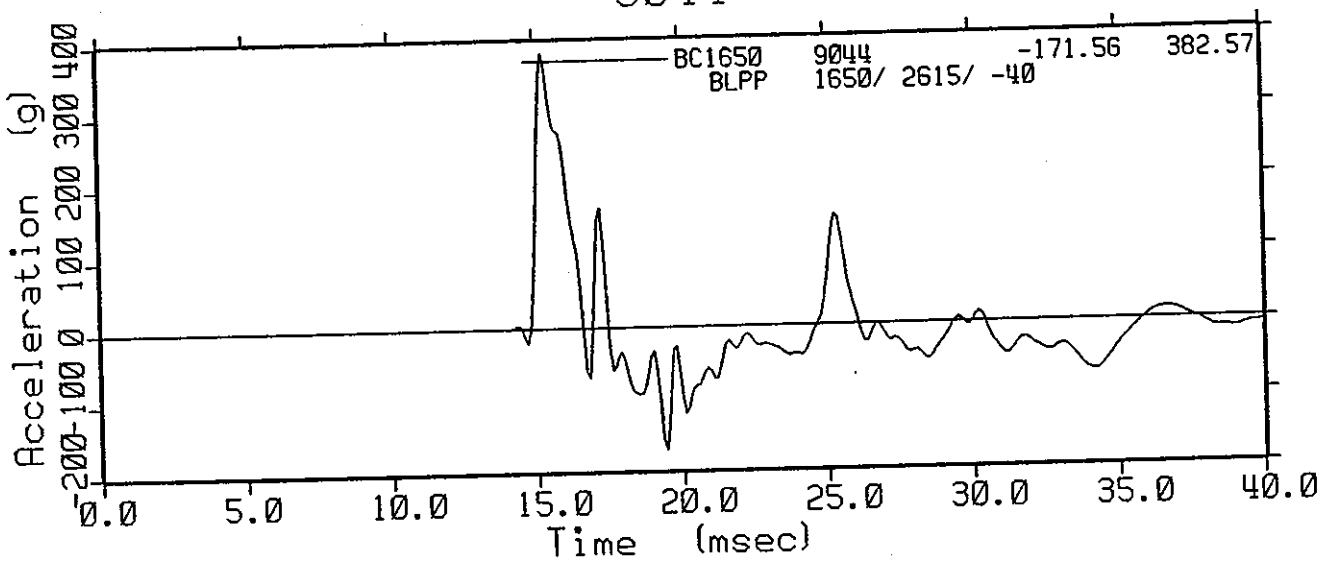

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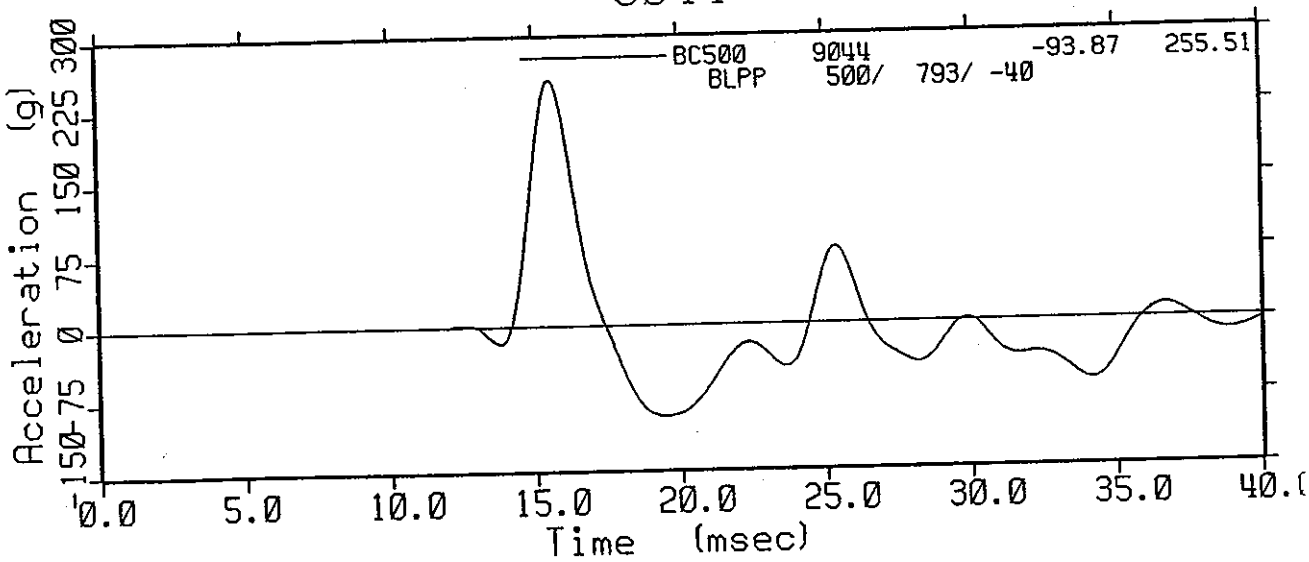

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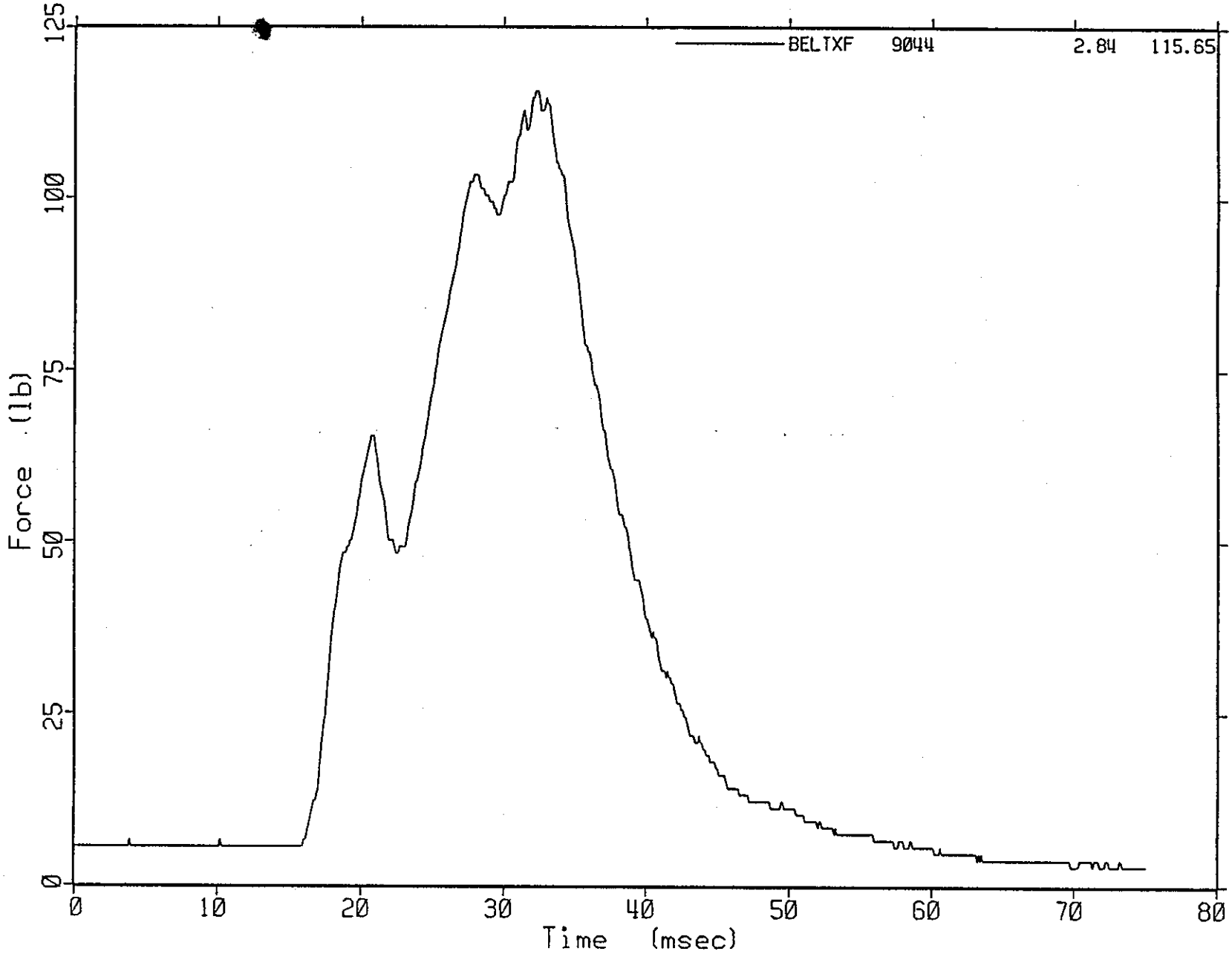

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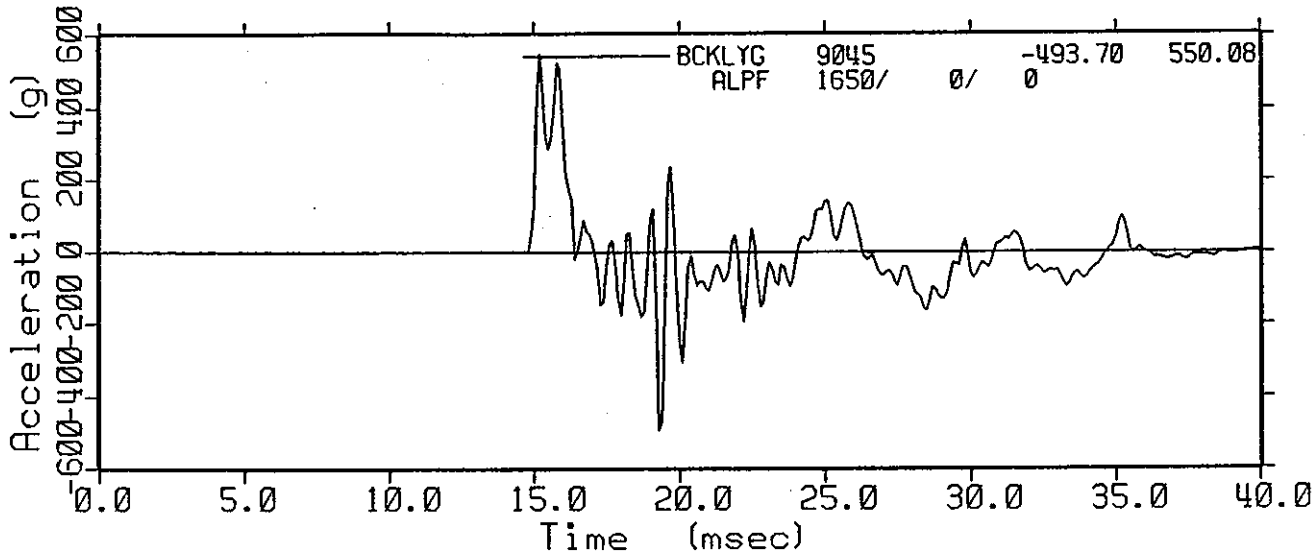

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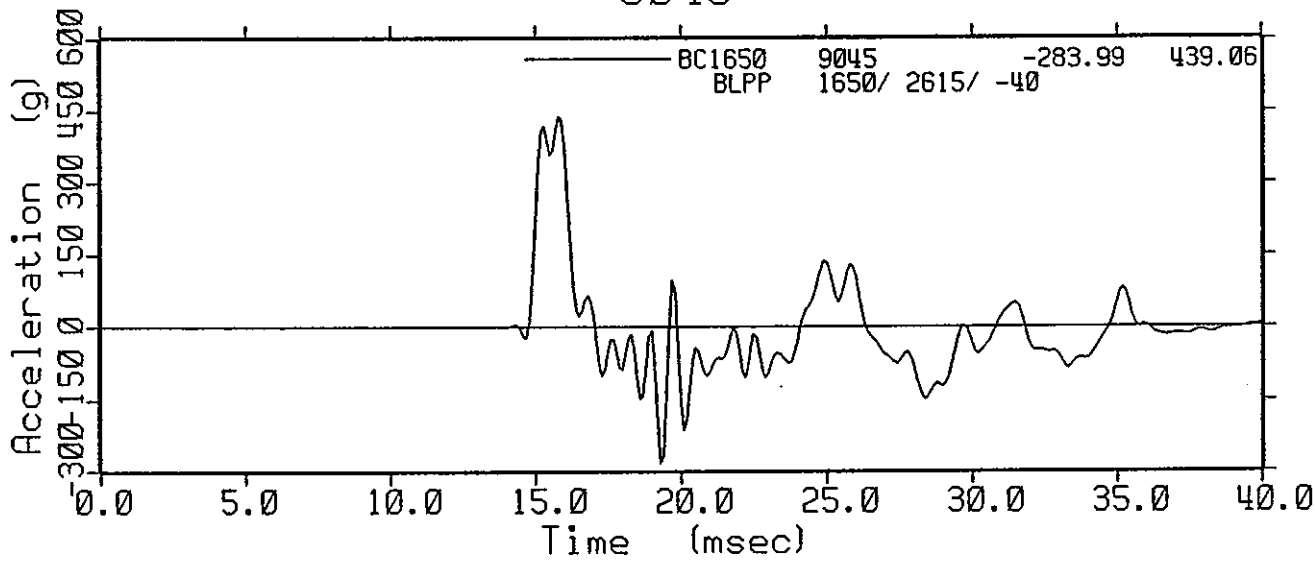

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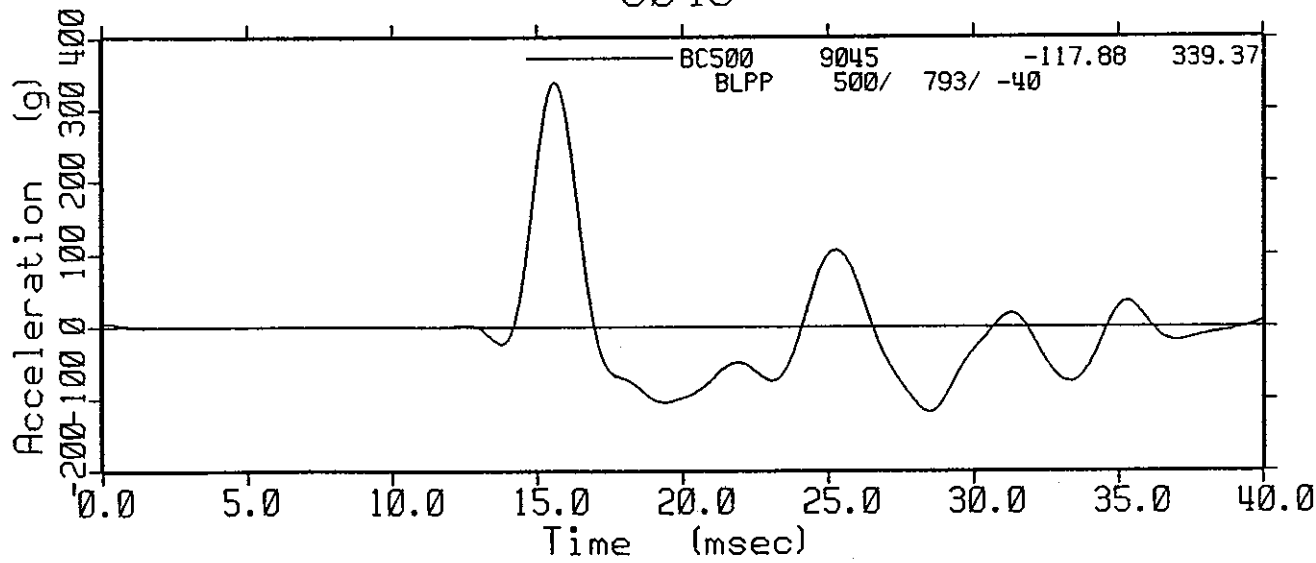

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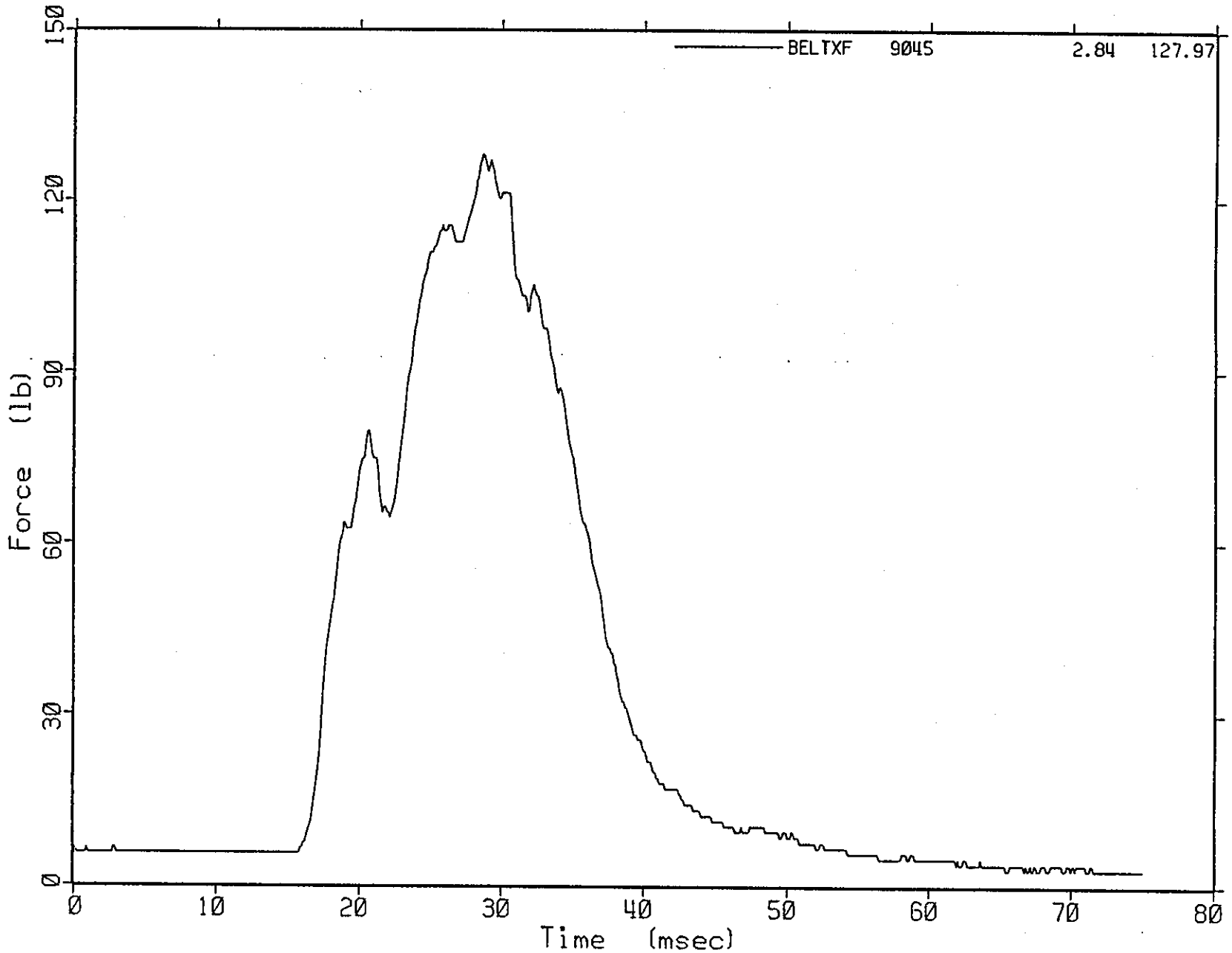

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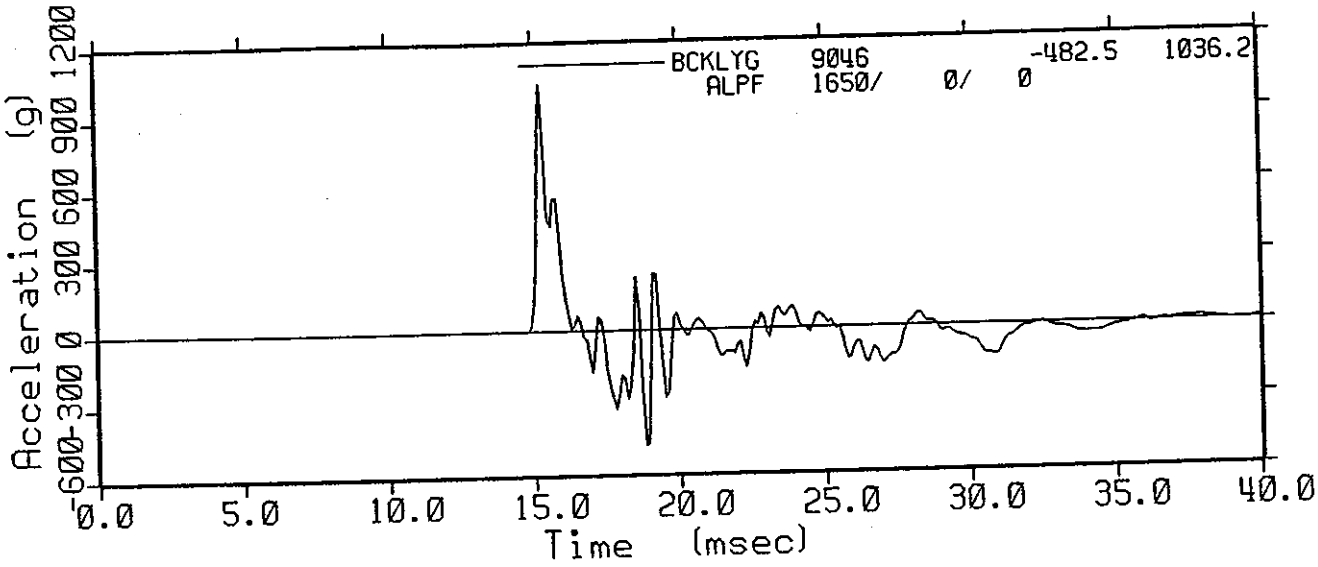

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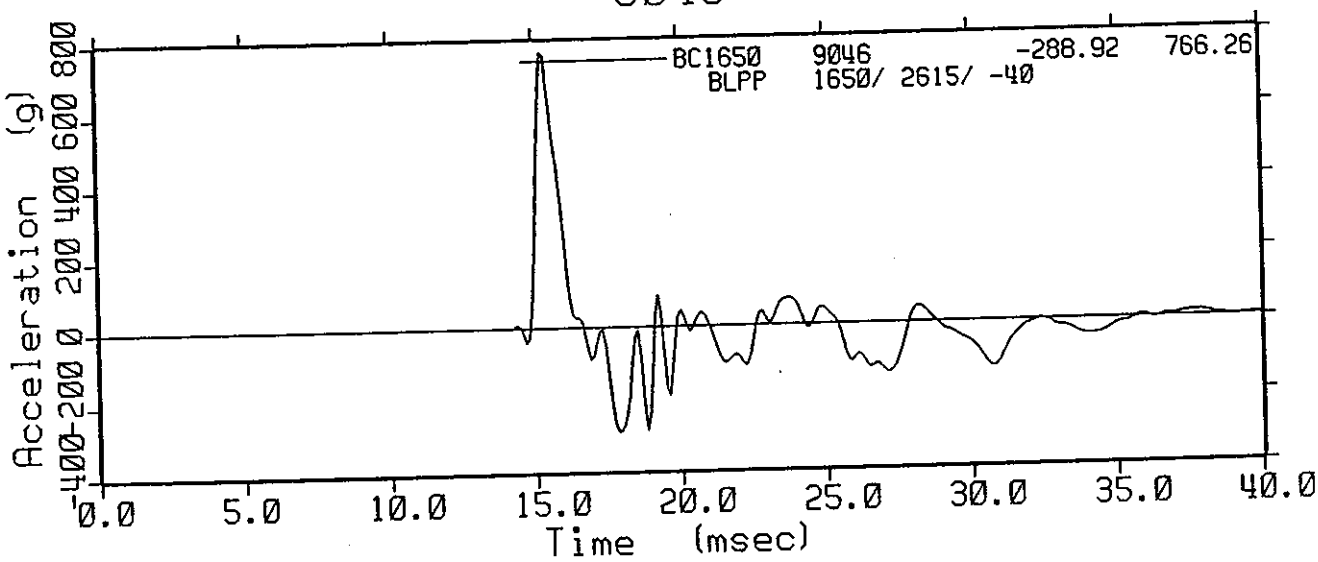

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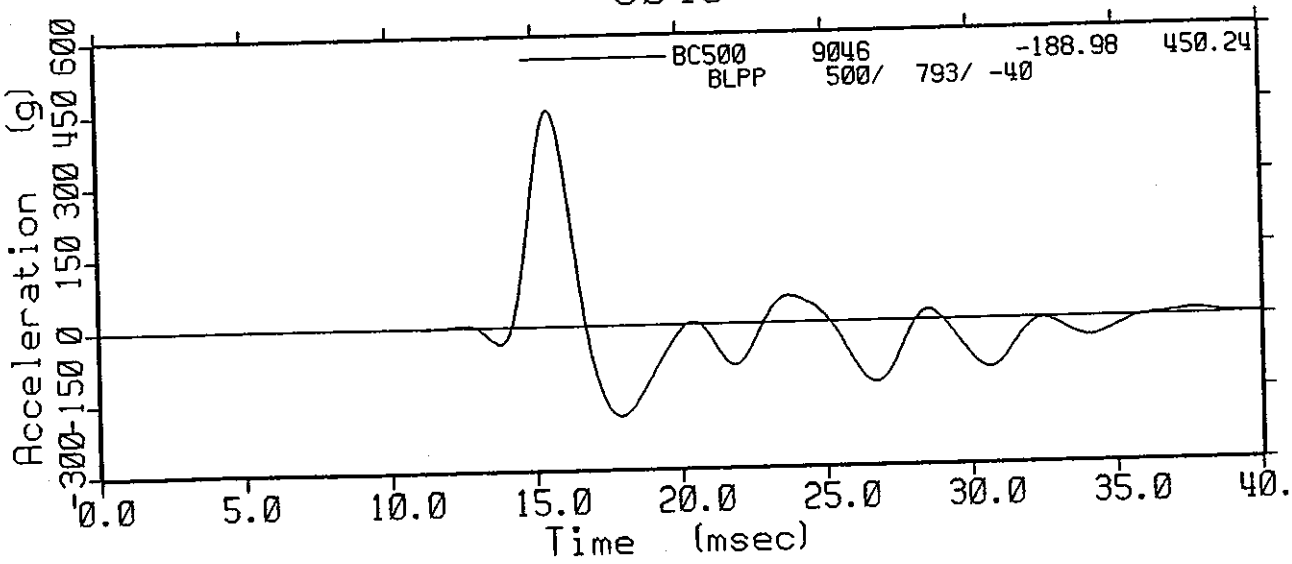

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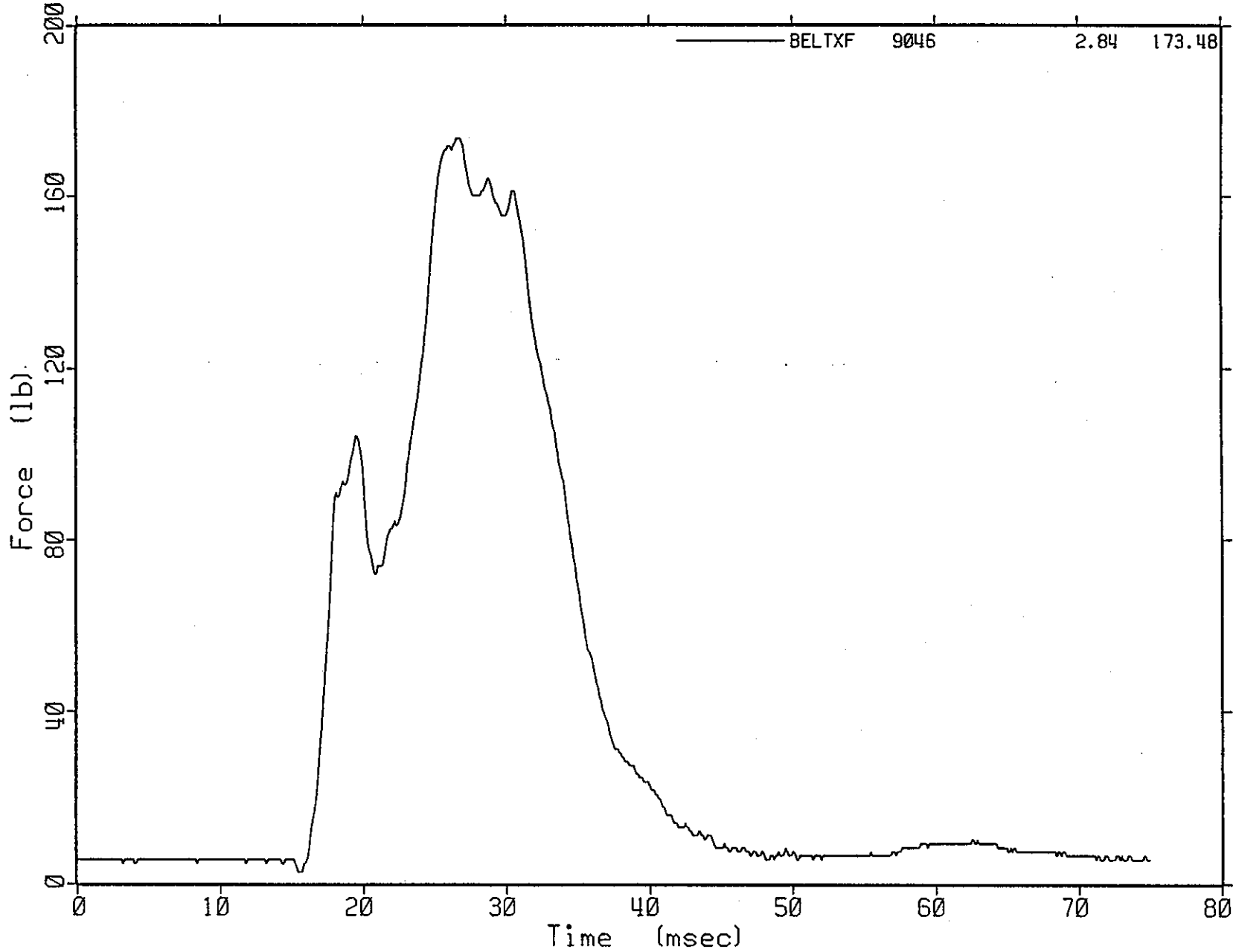

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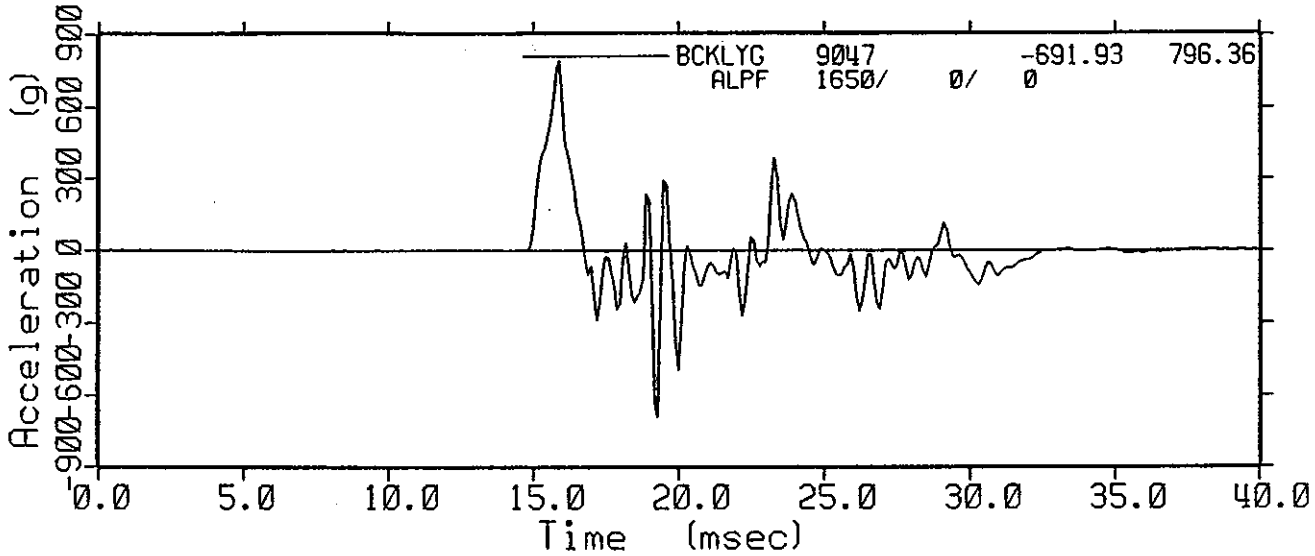

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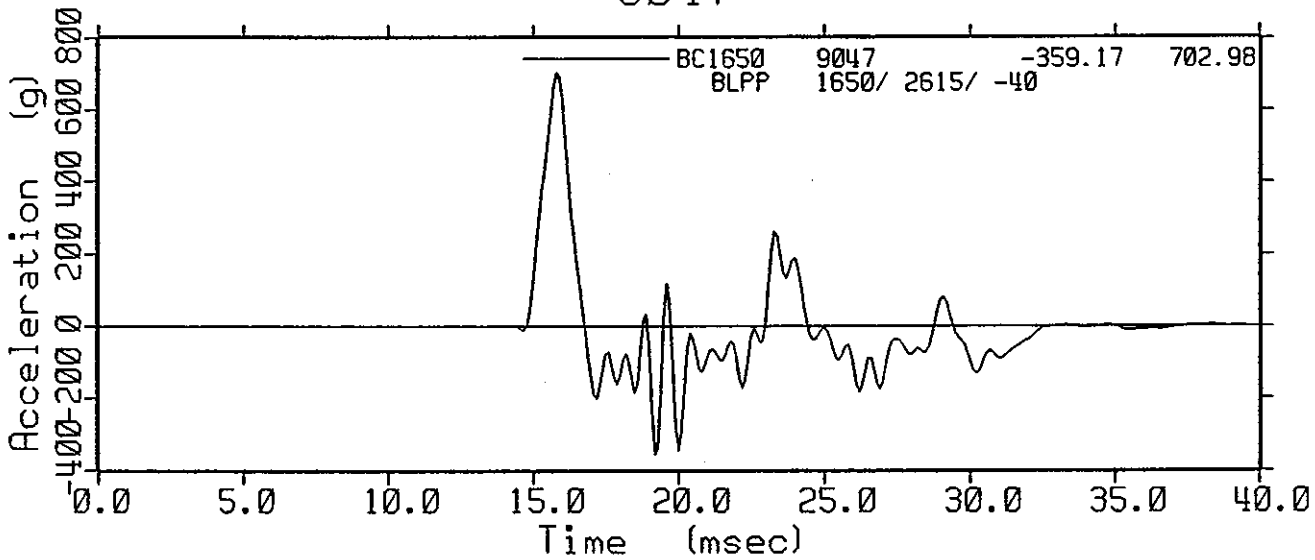

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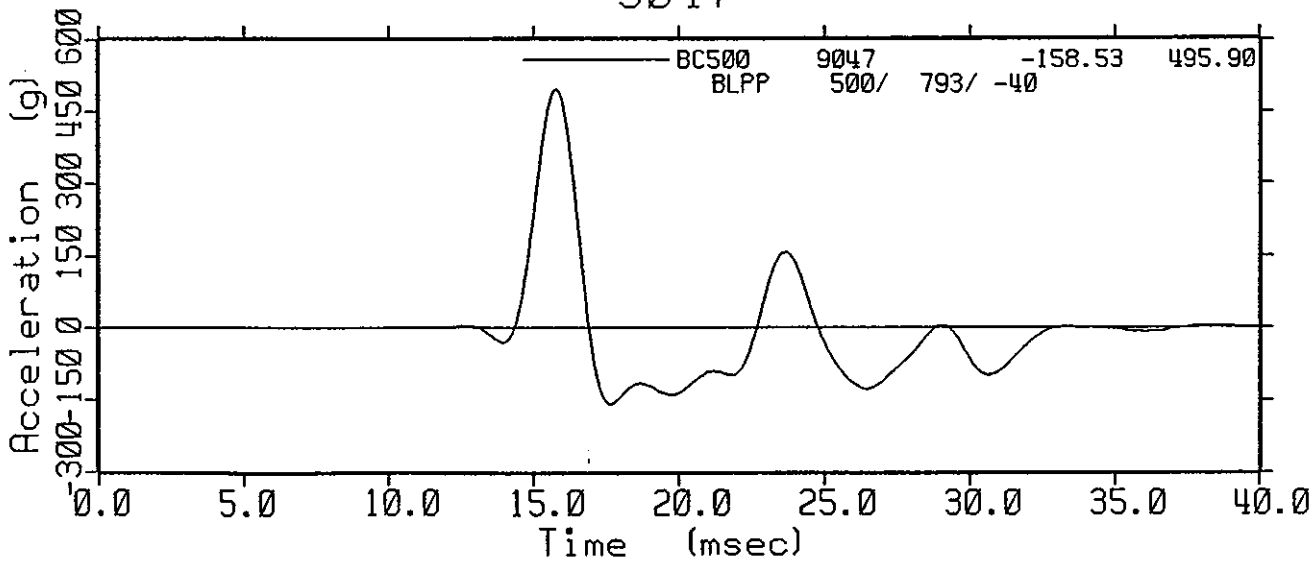

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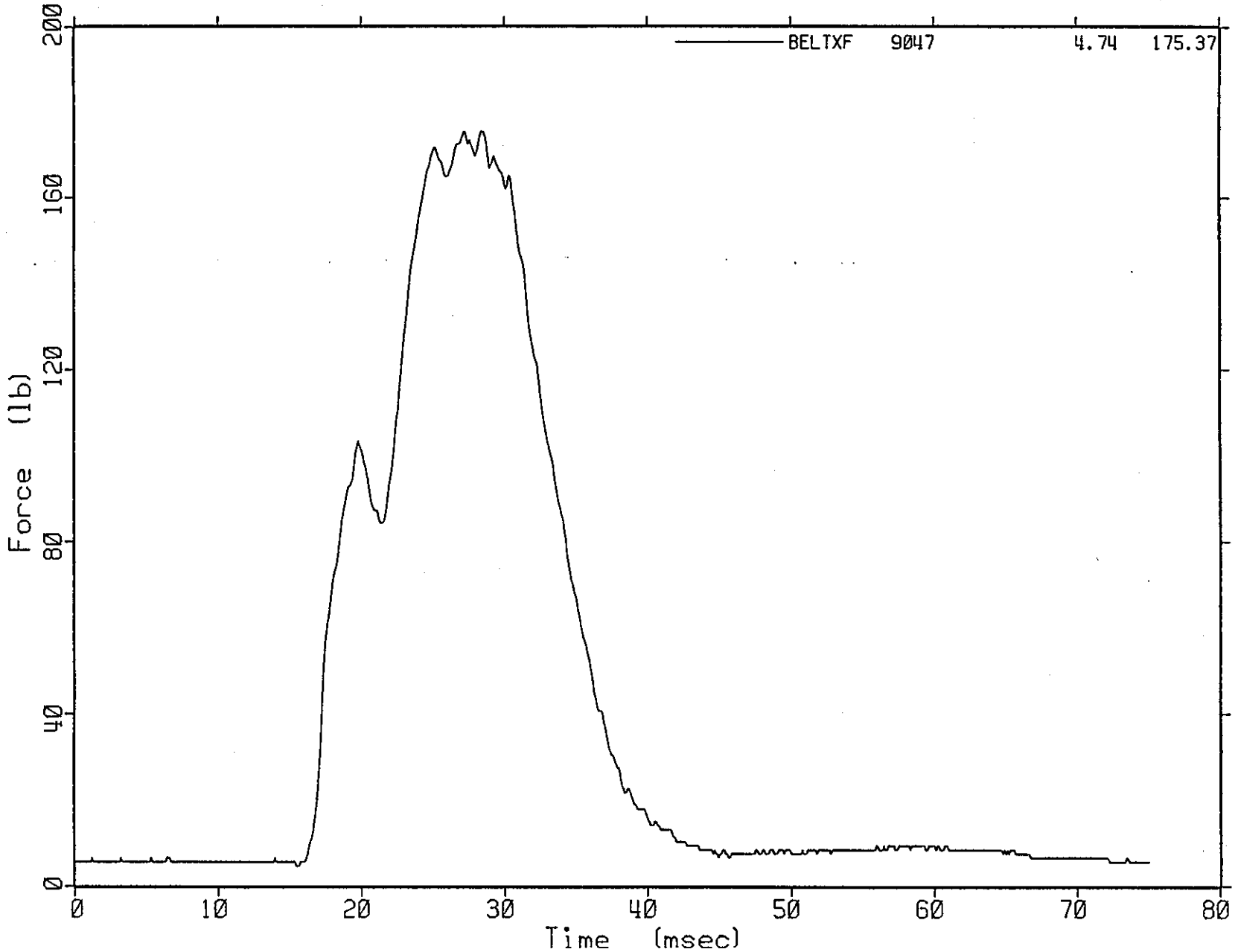

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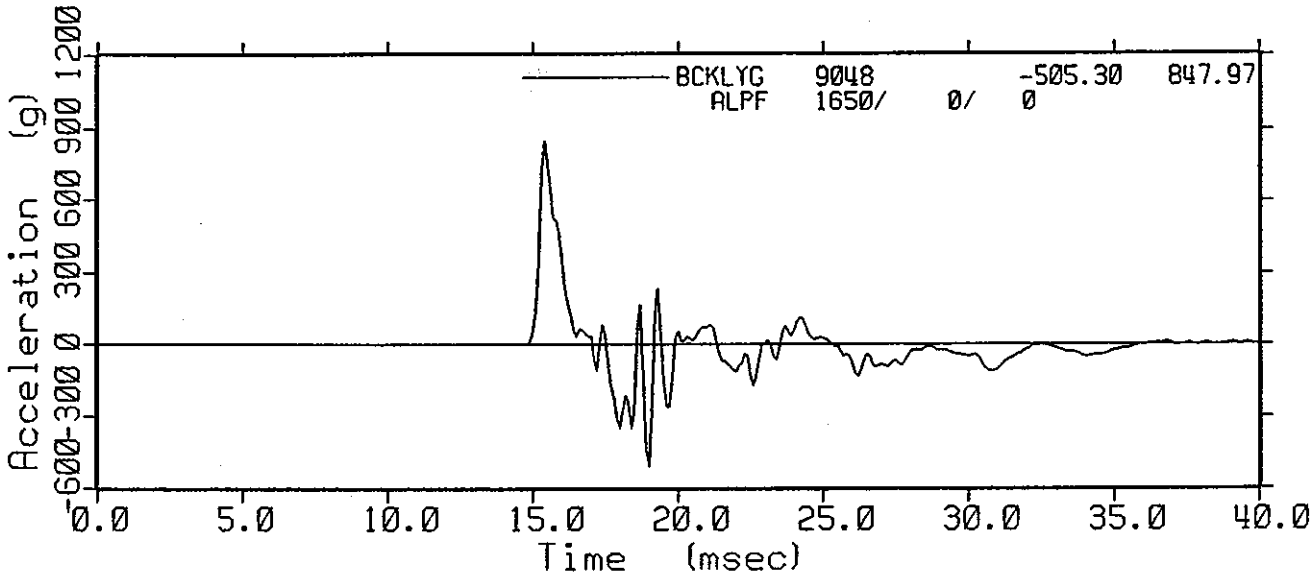

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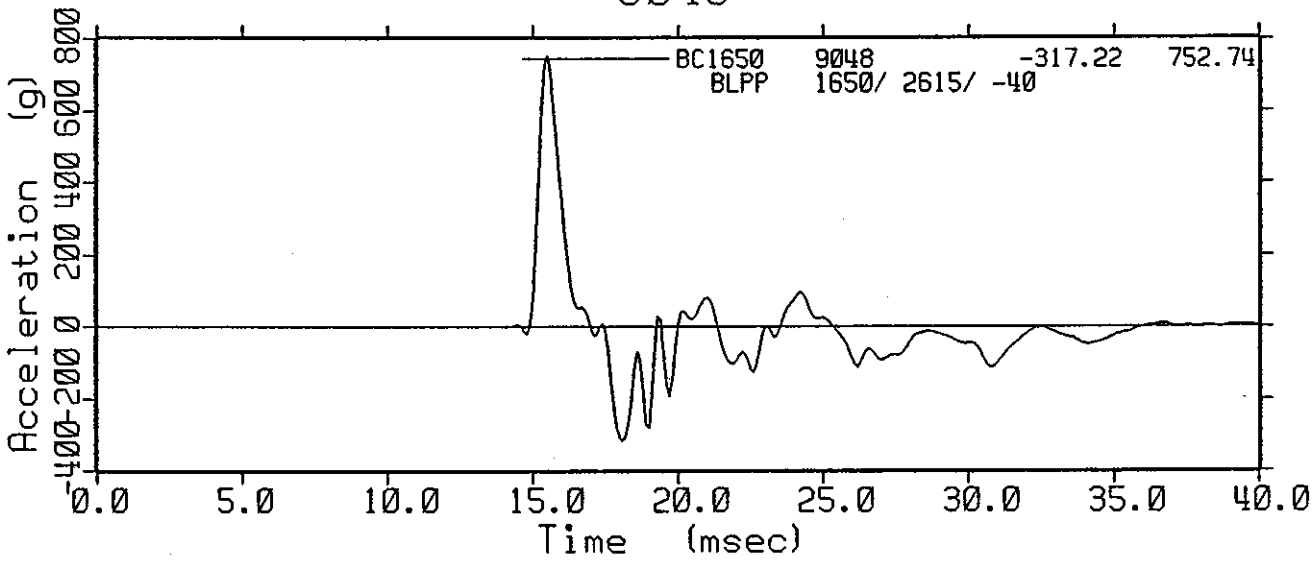

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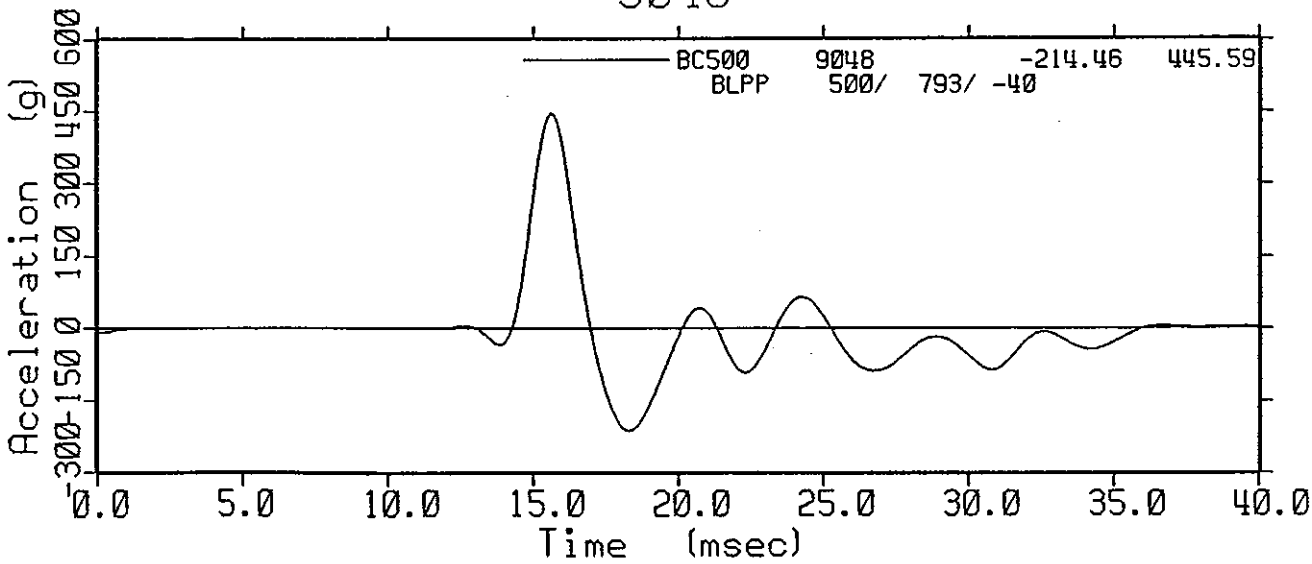

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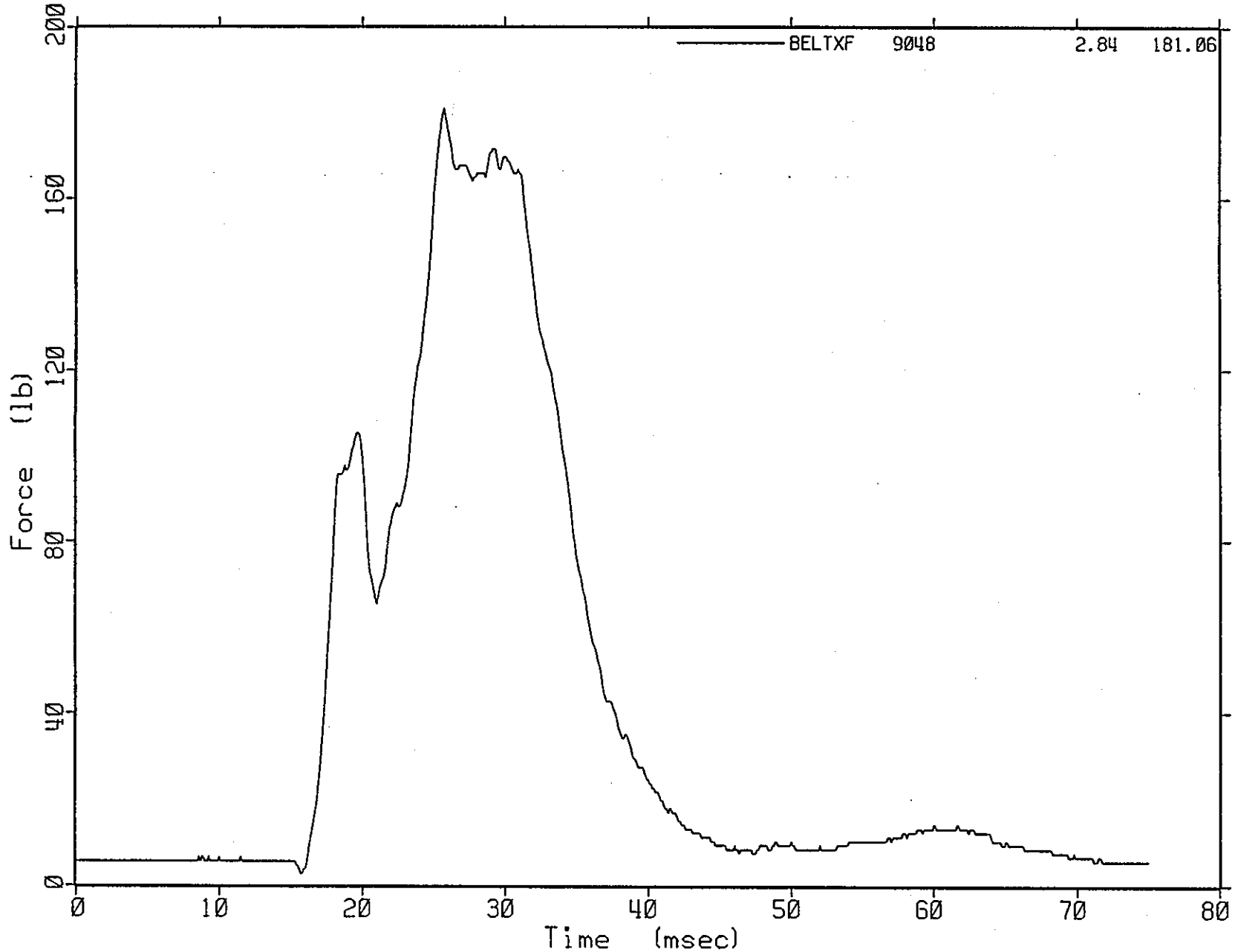

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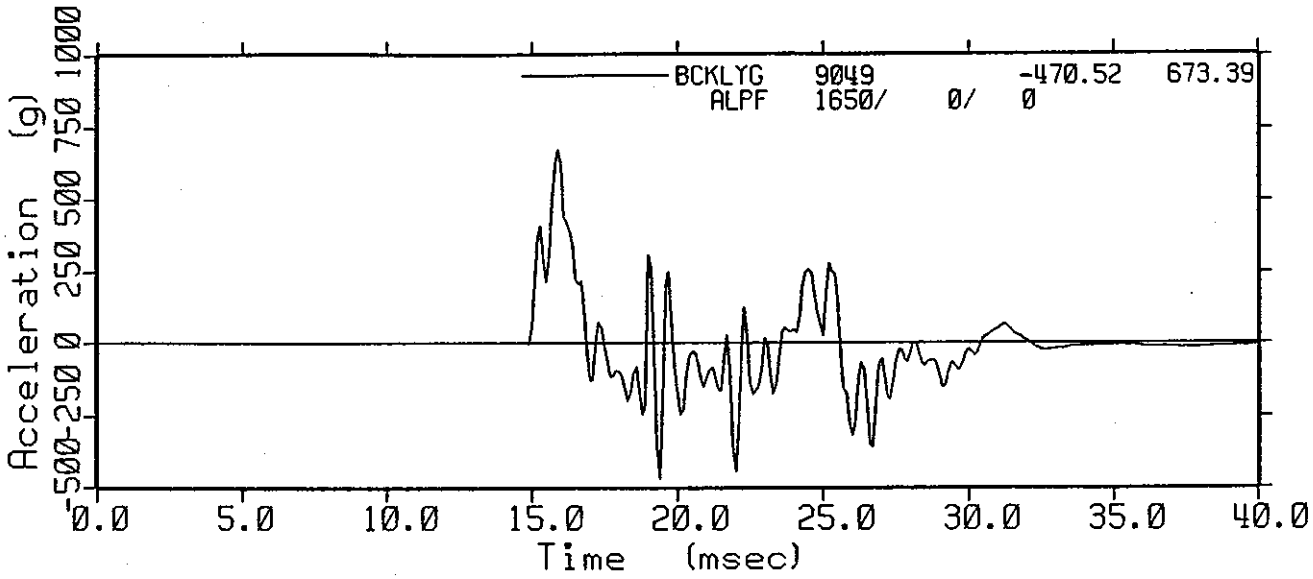

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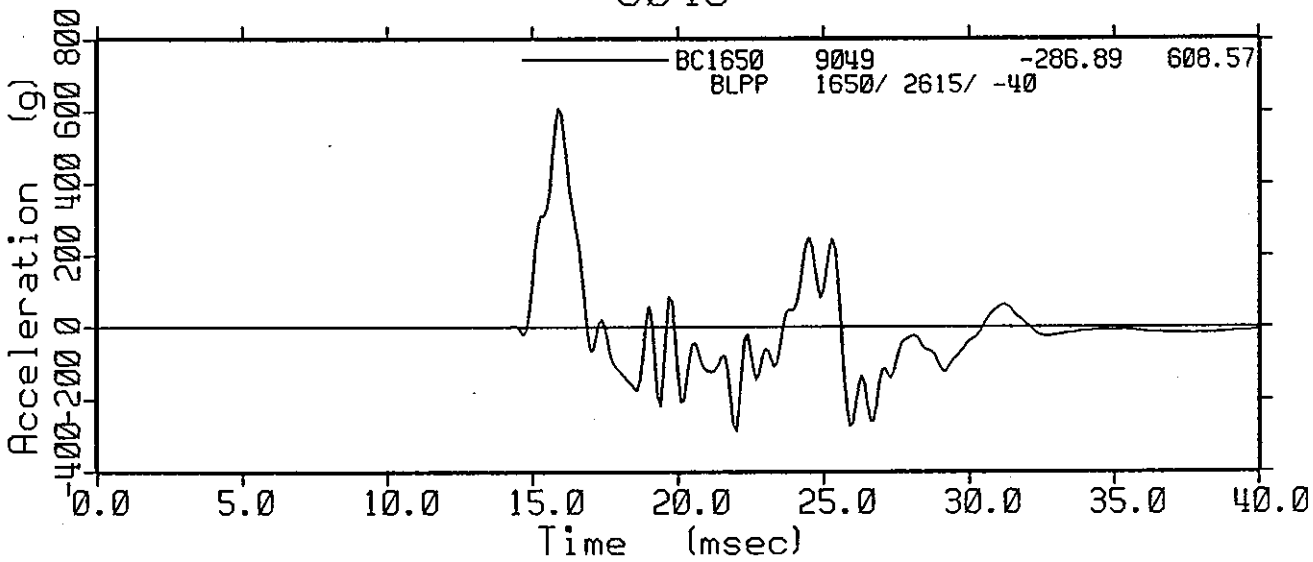

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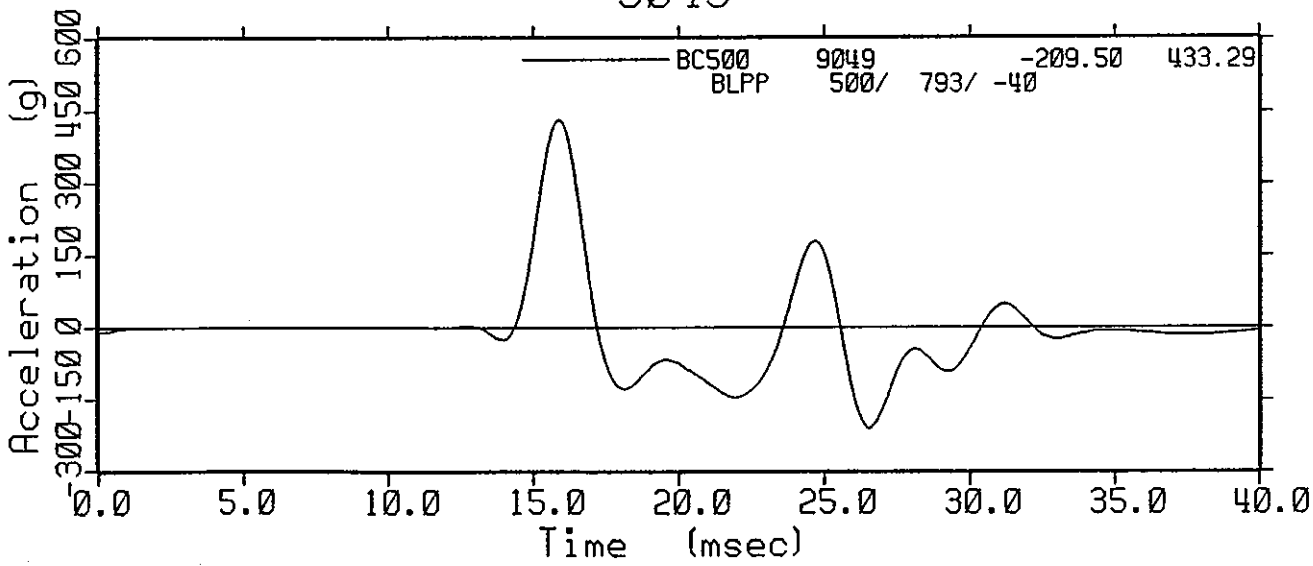

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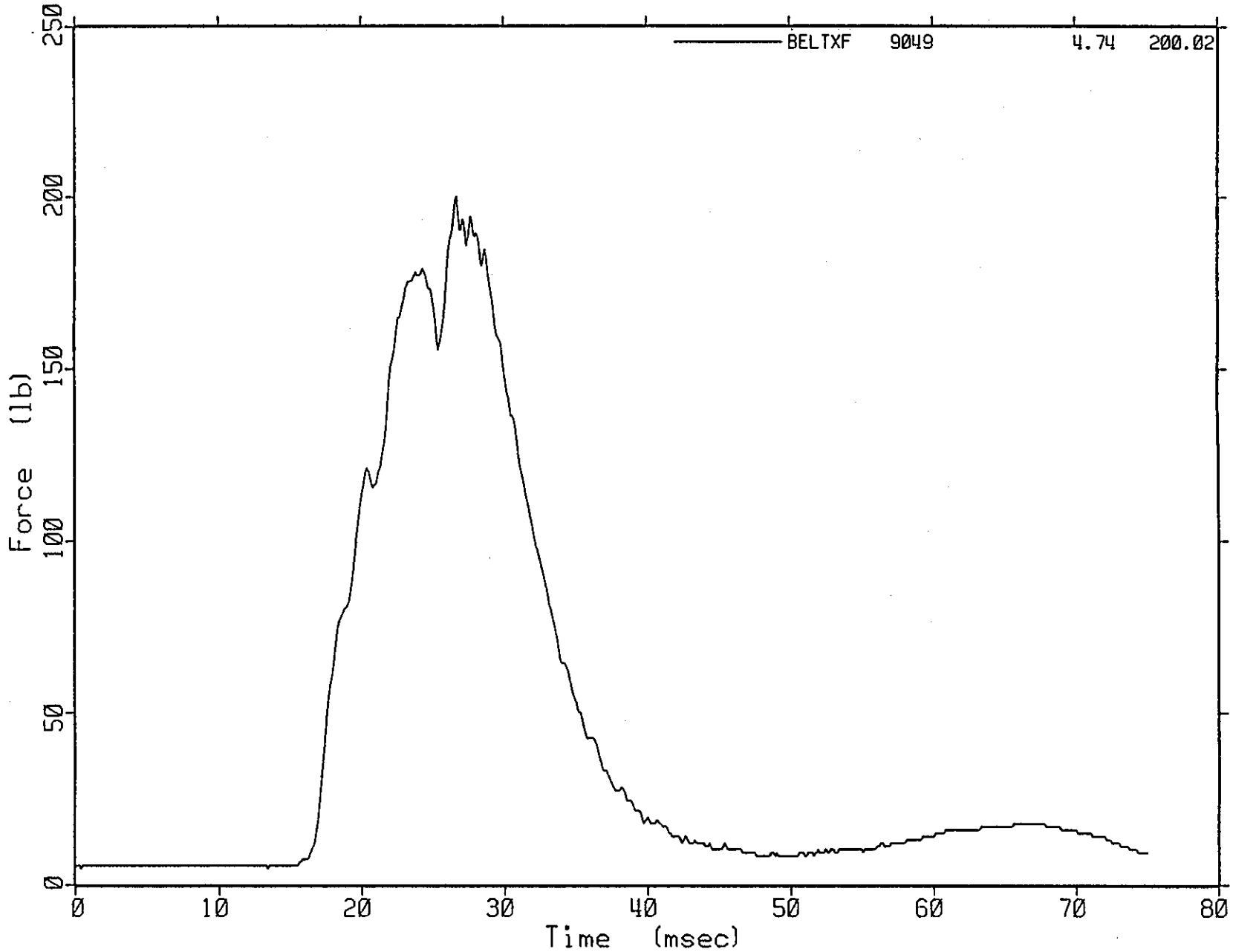

TEST 9049 - FORCE

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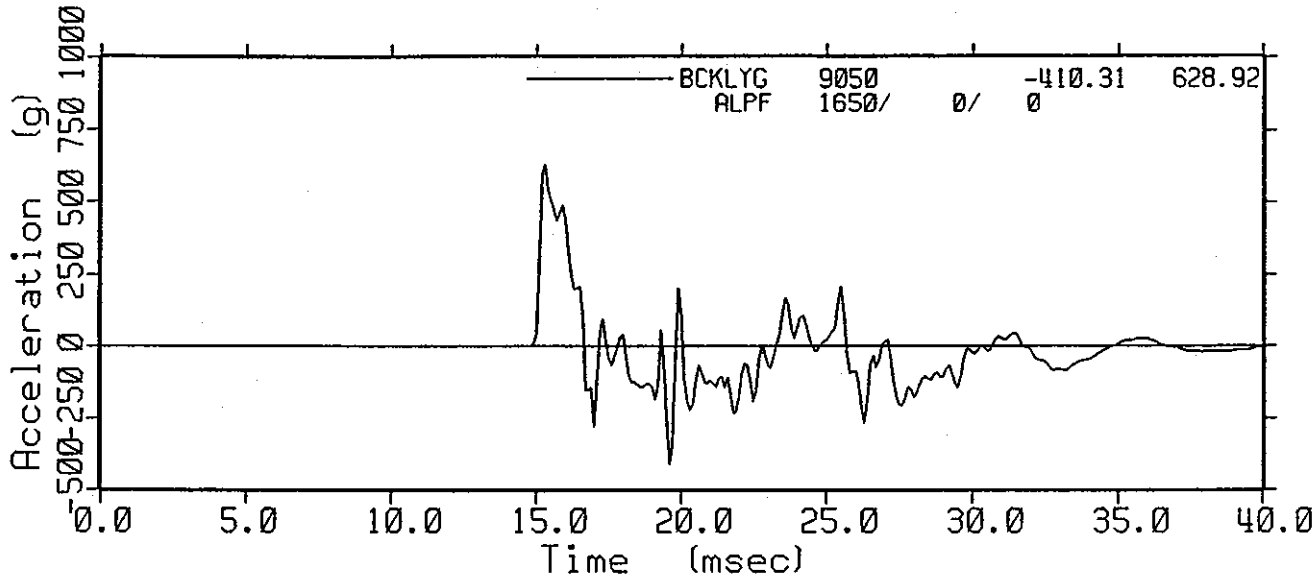

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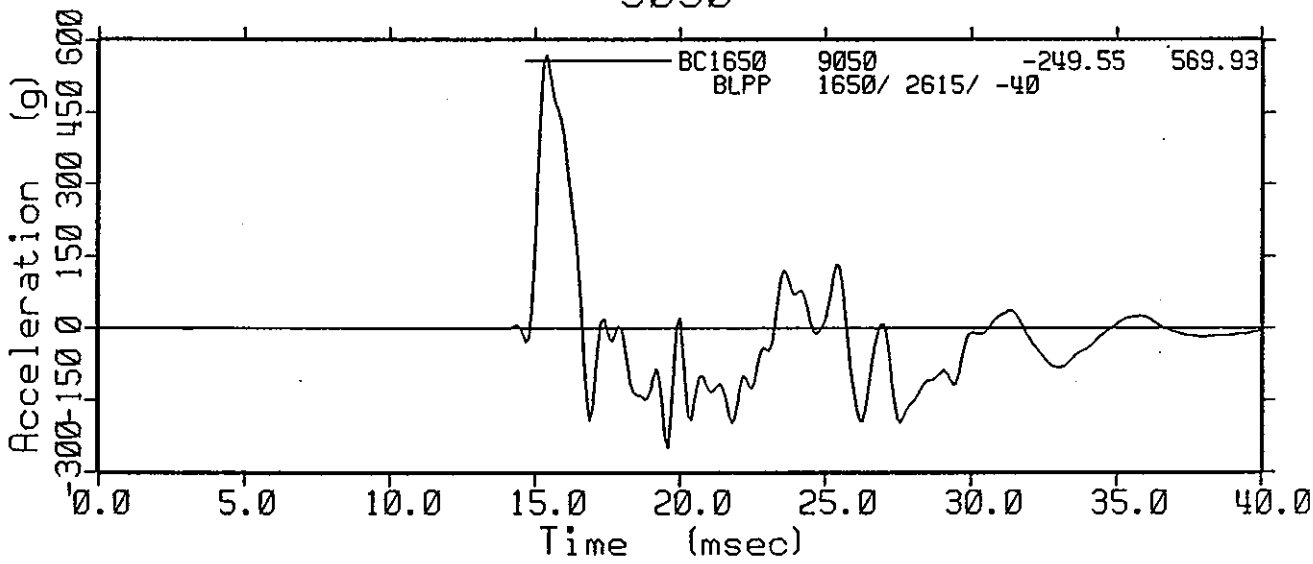

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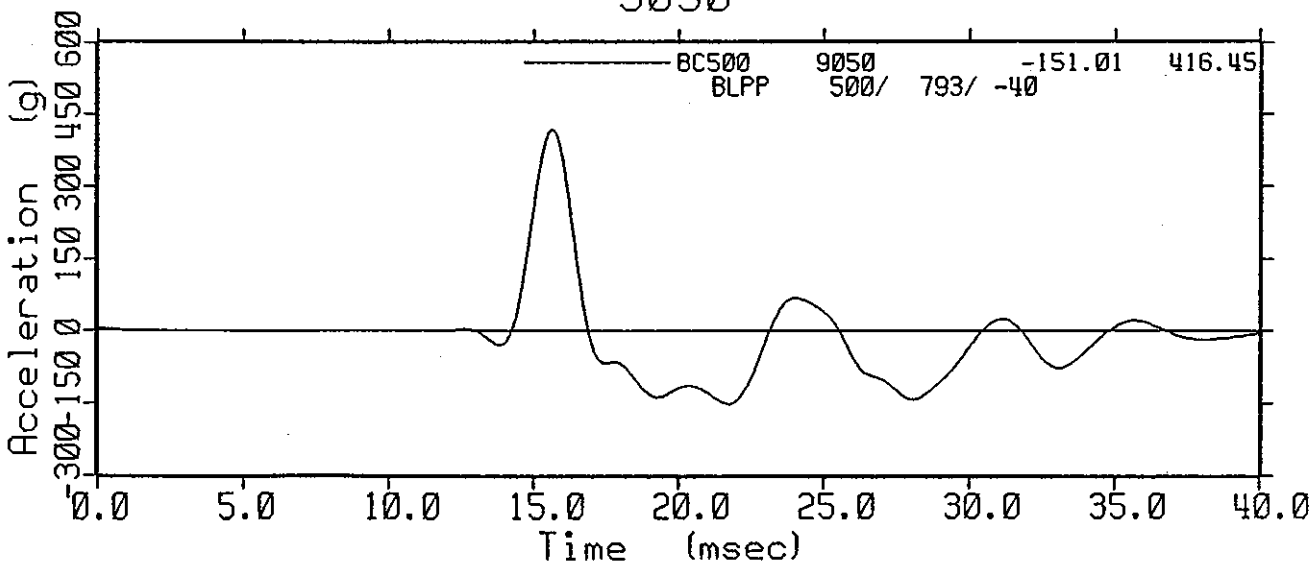

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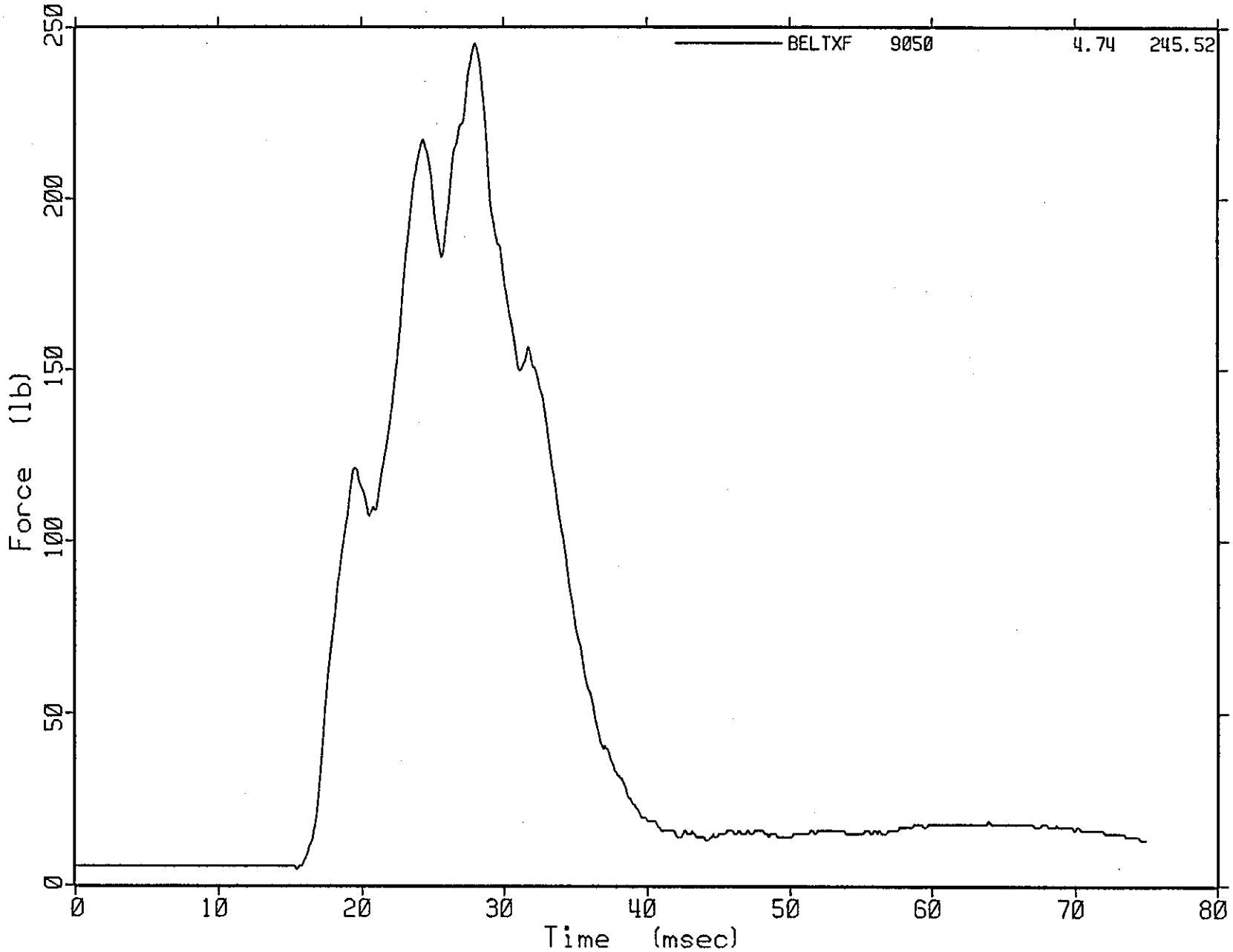

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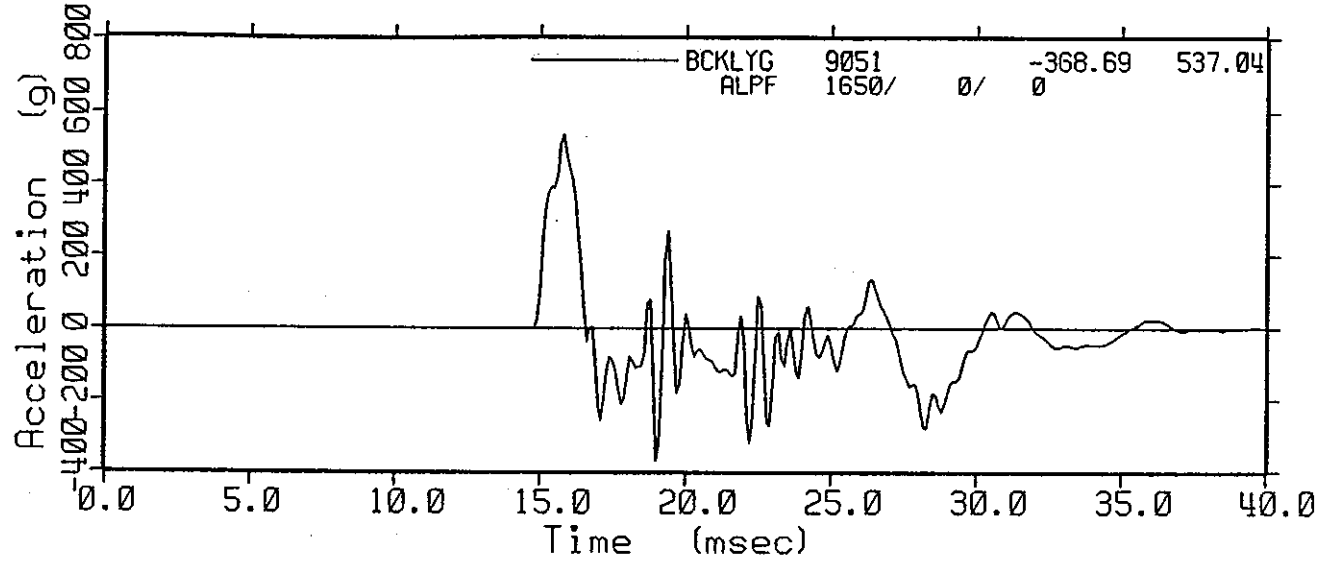

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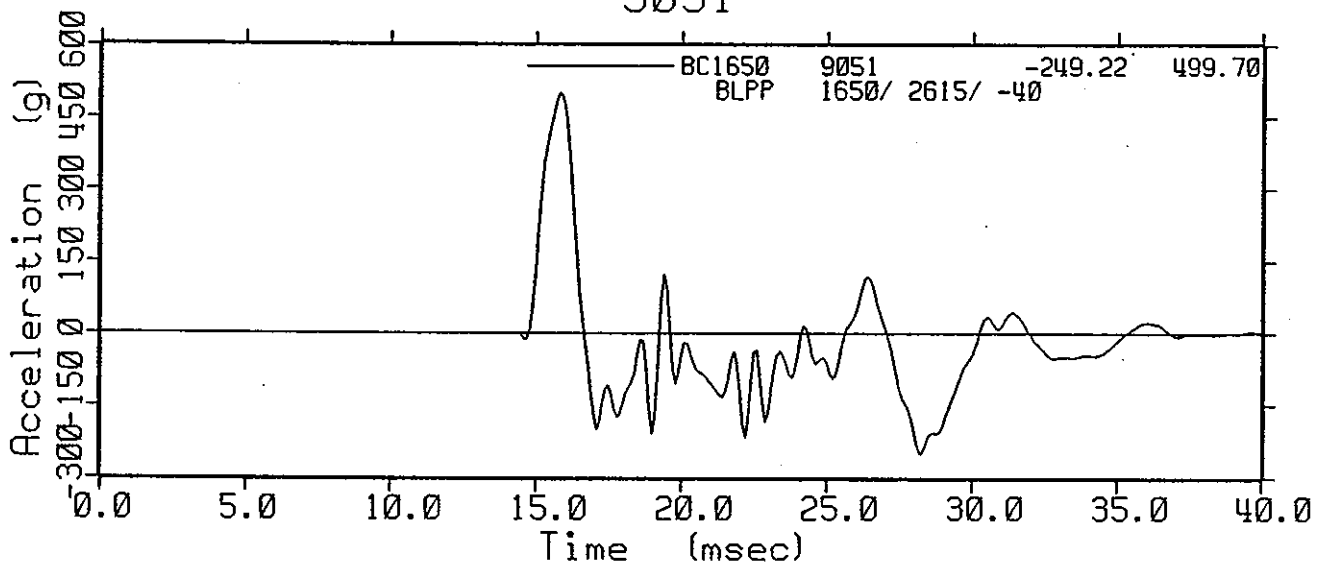

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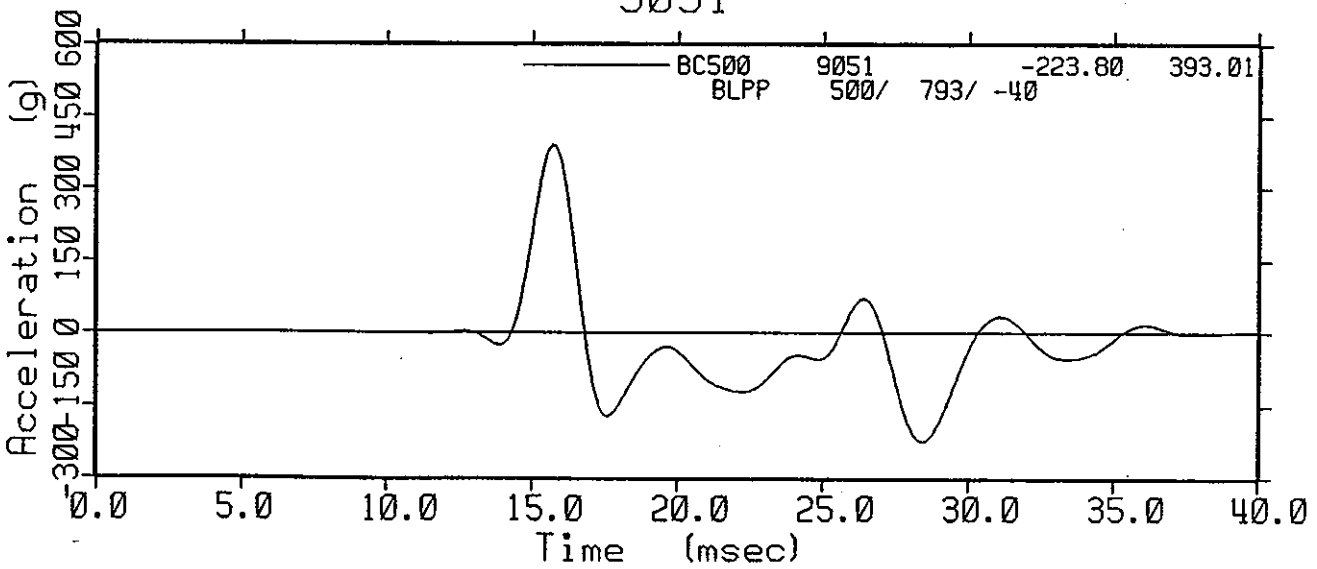

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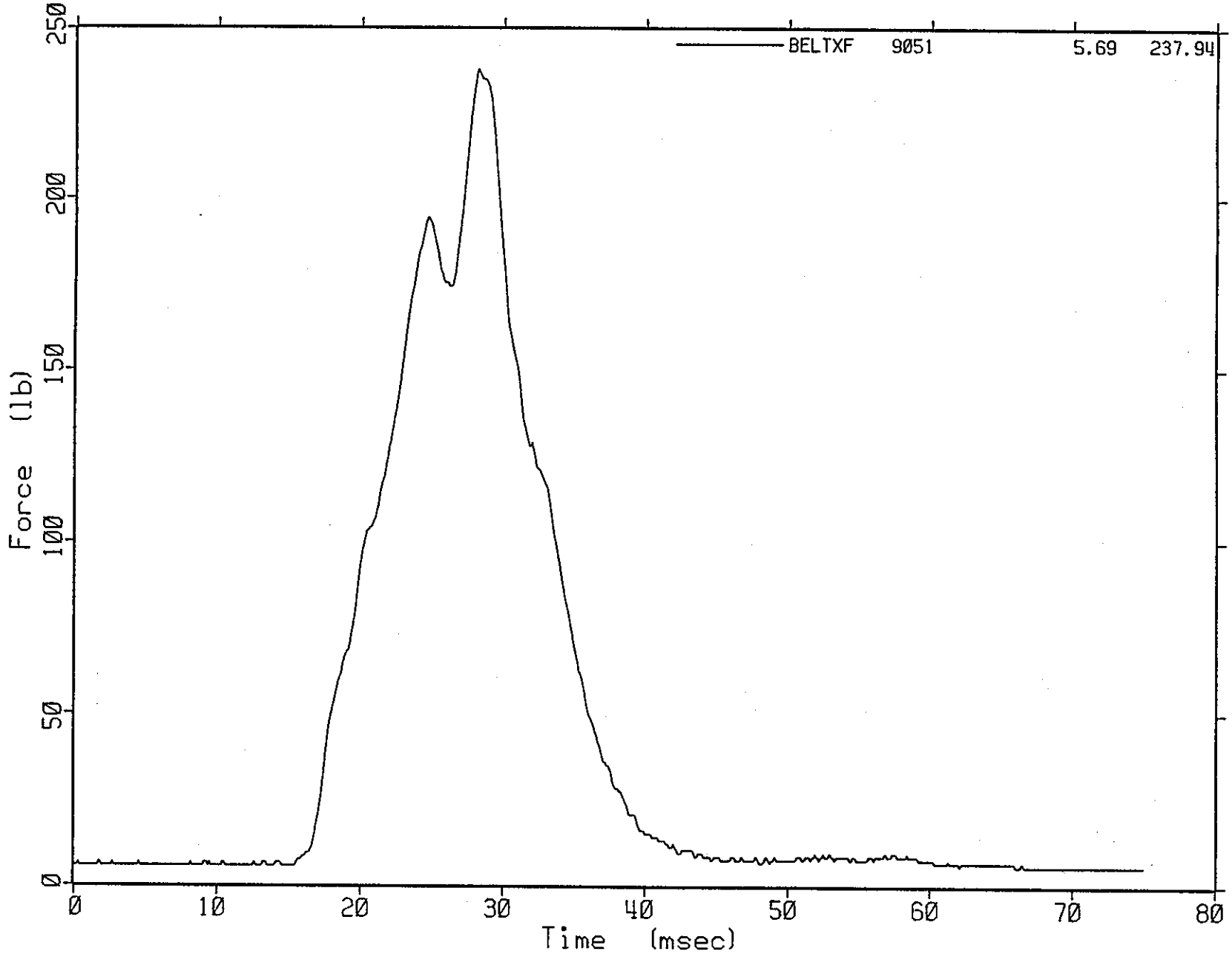

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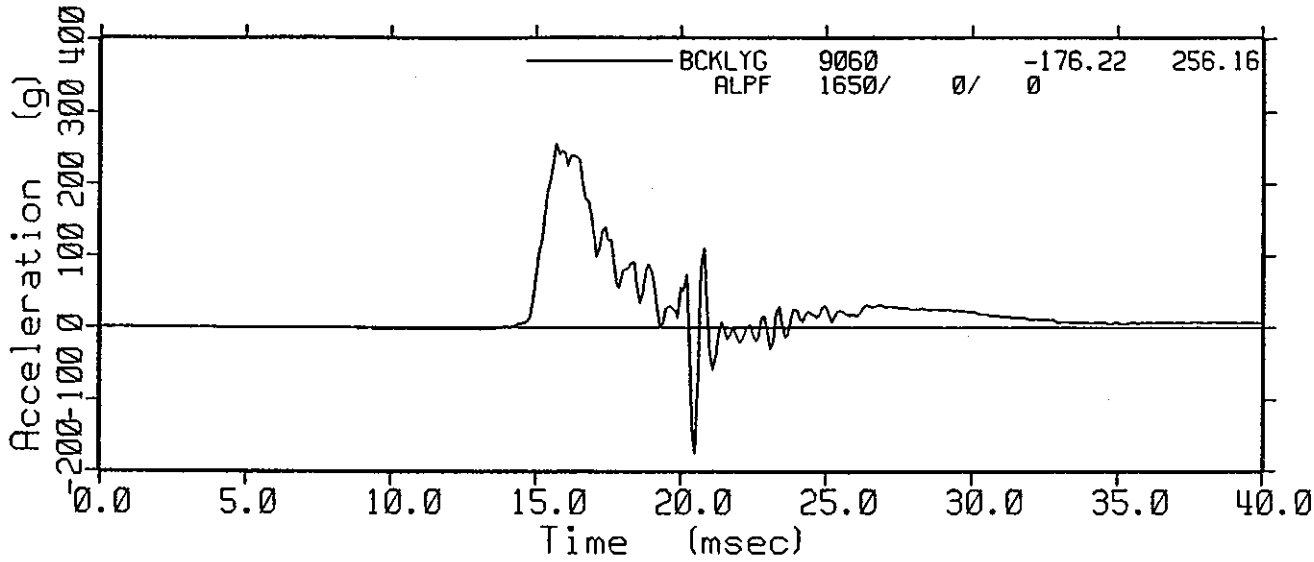

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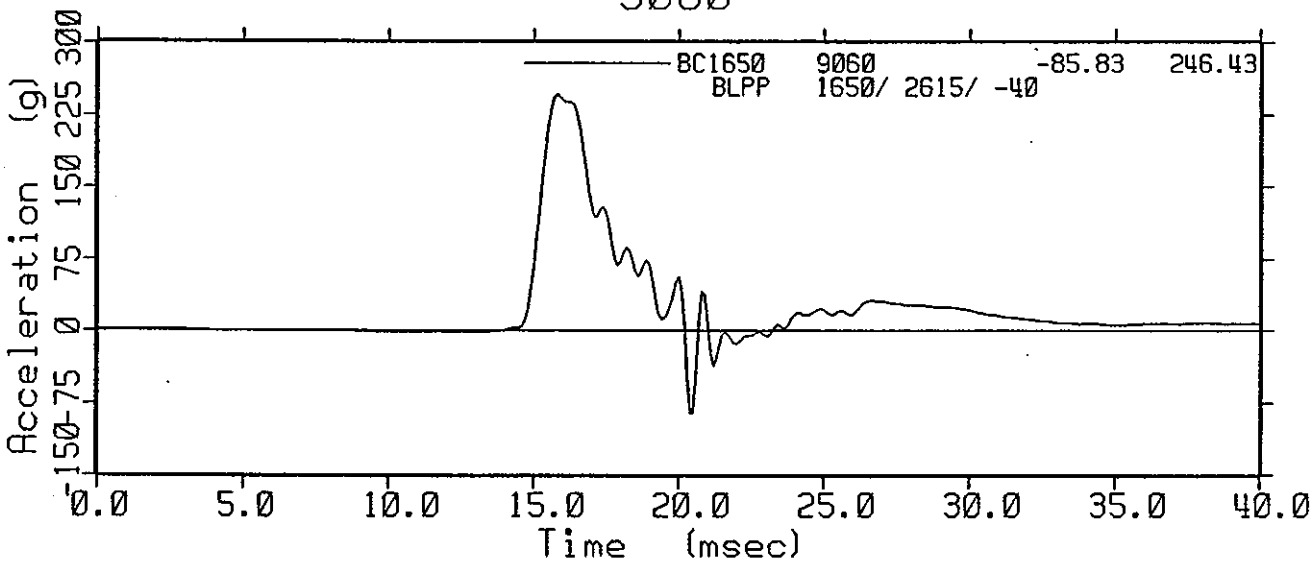

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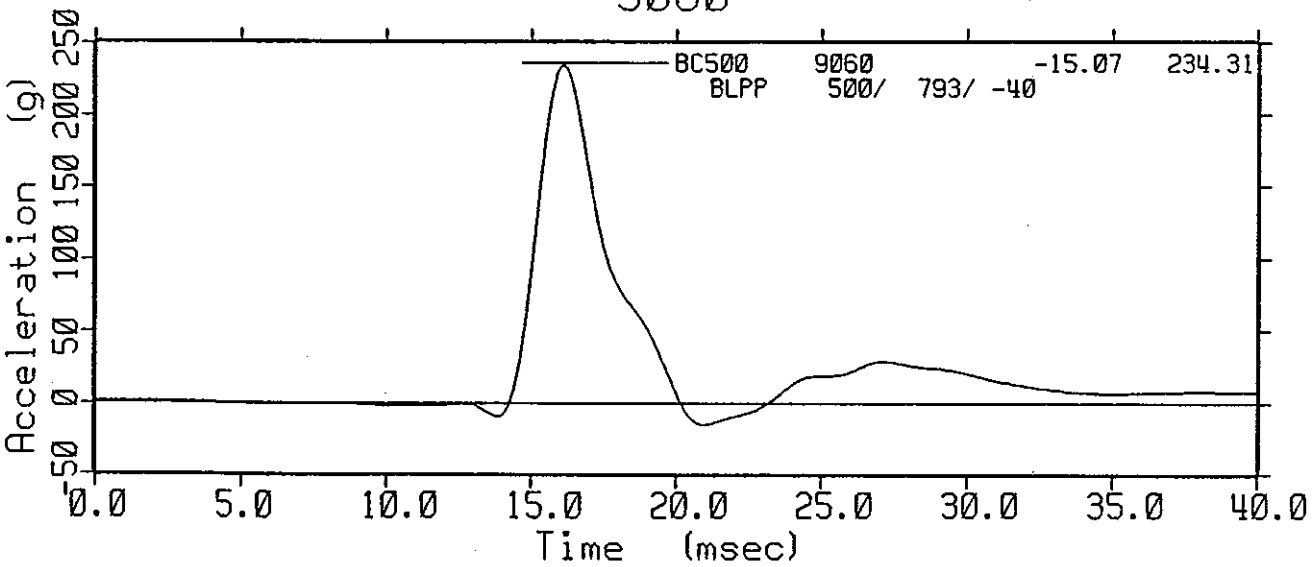

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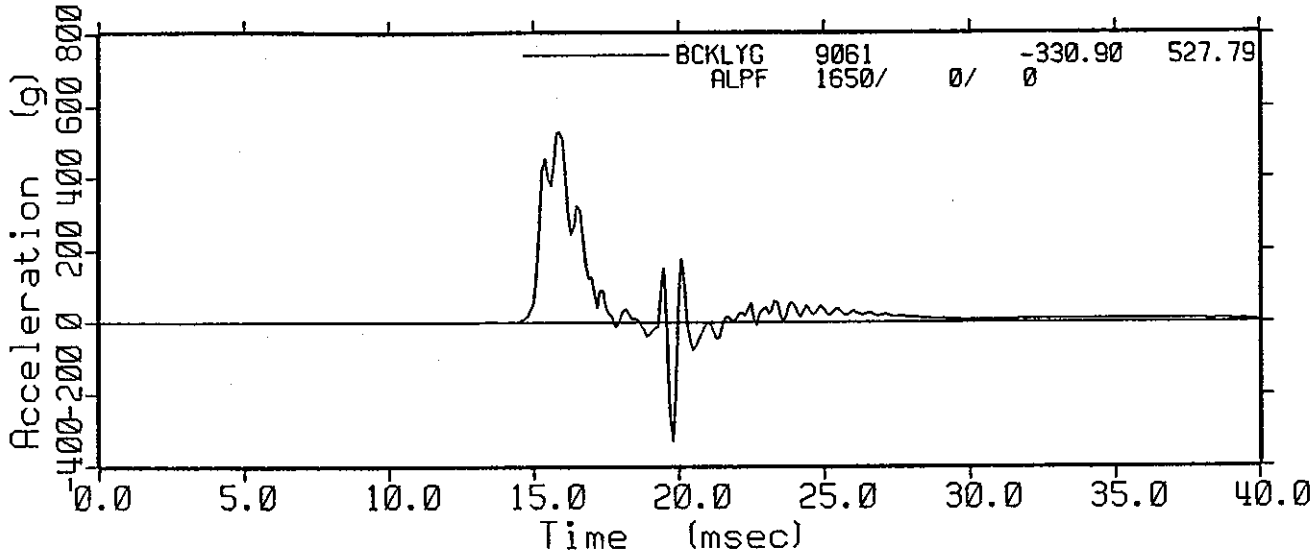

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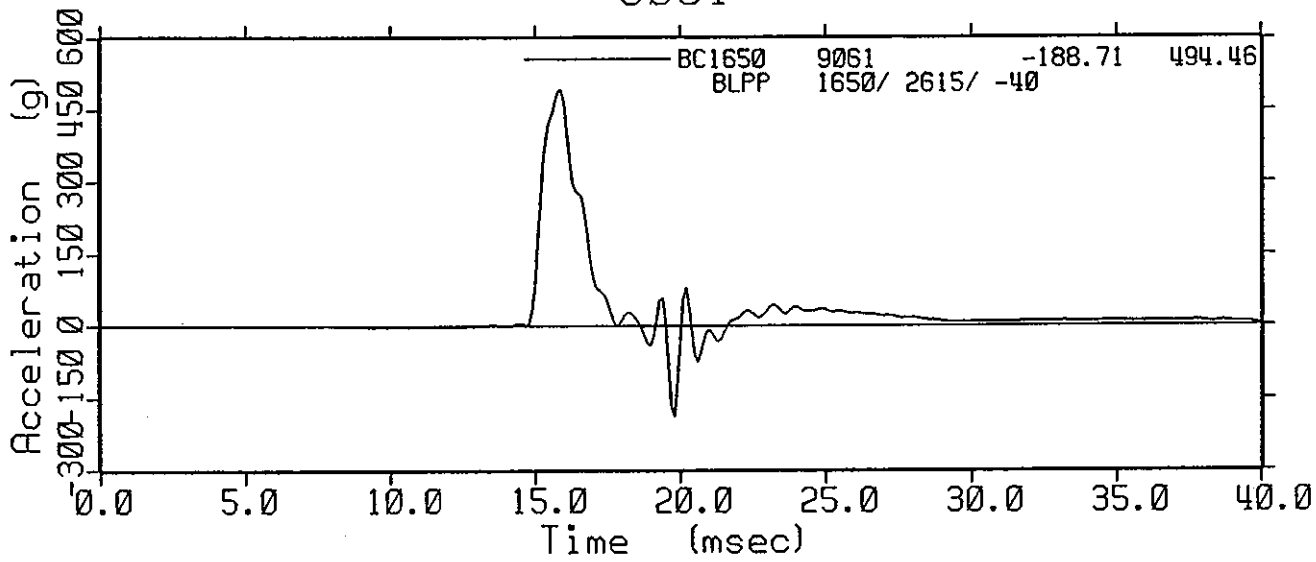

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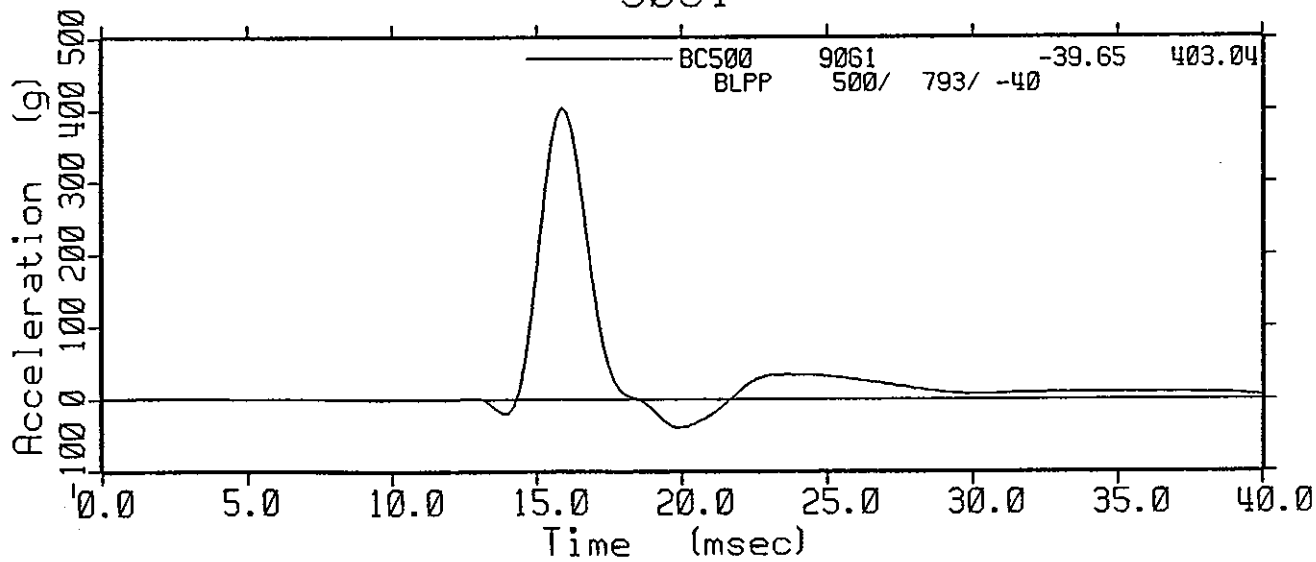

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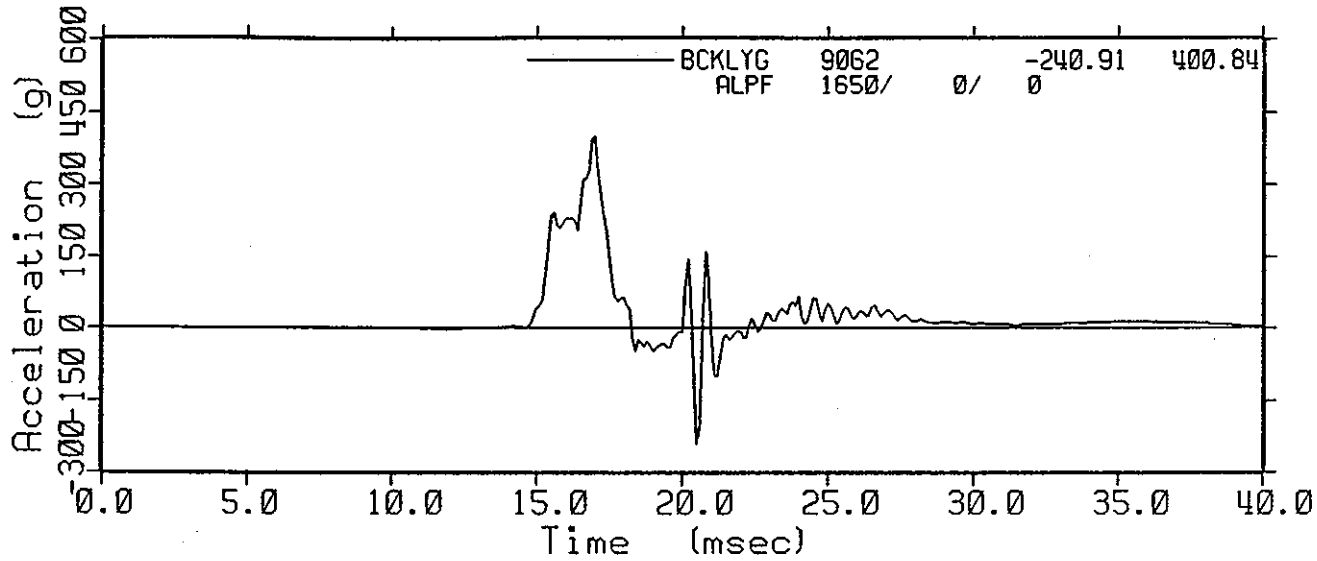

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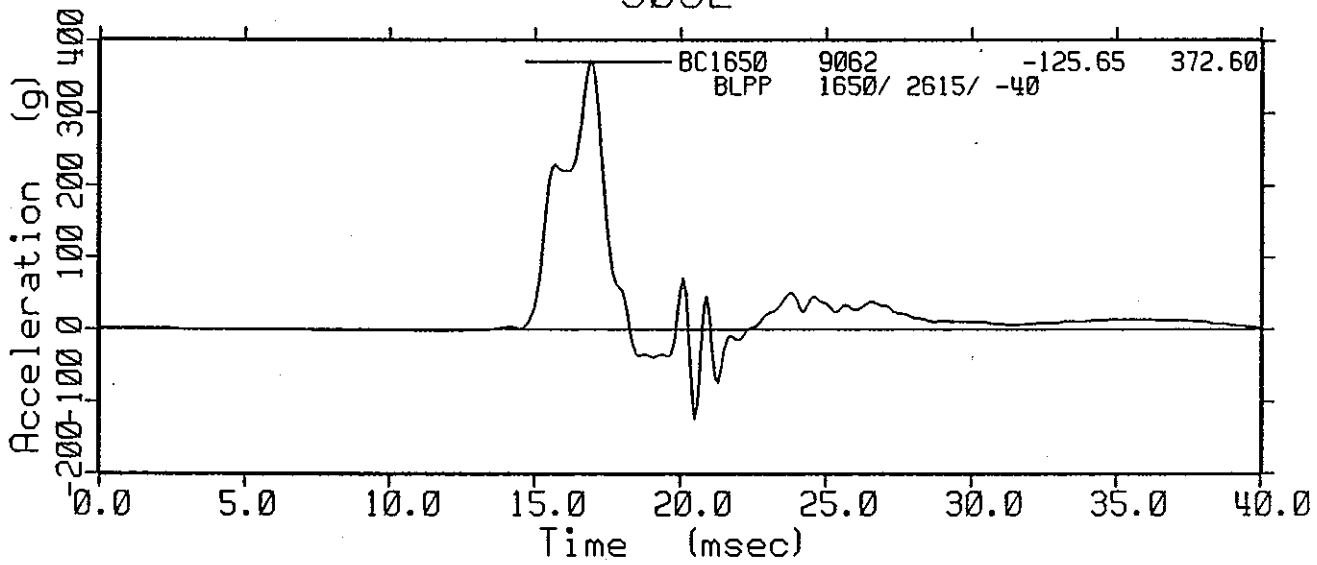

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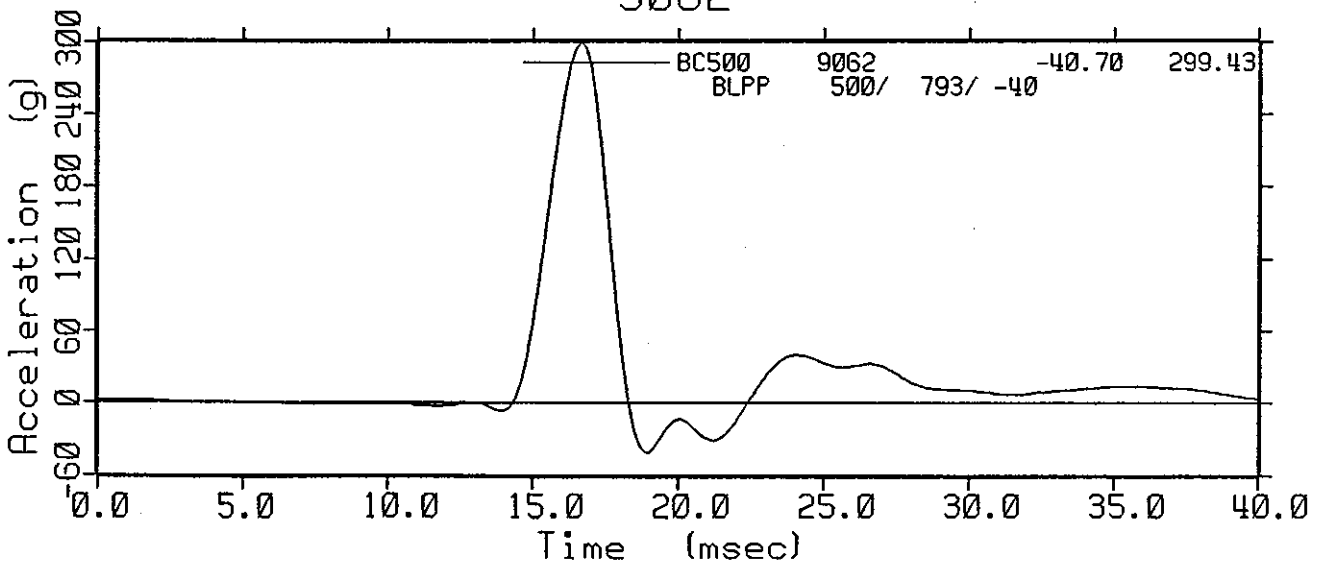

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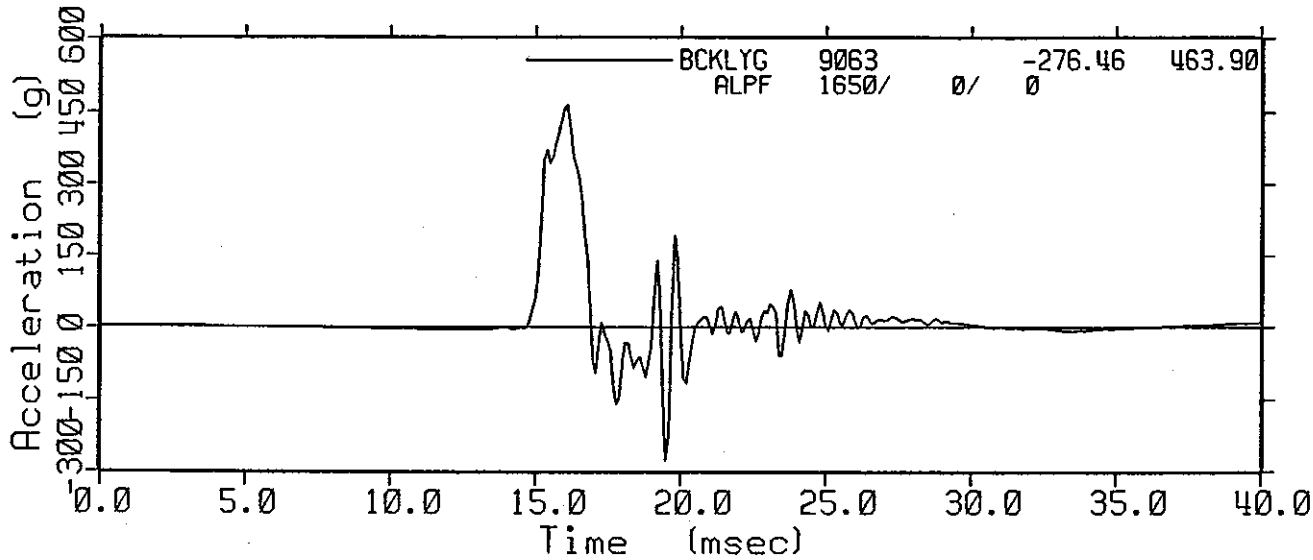

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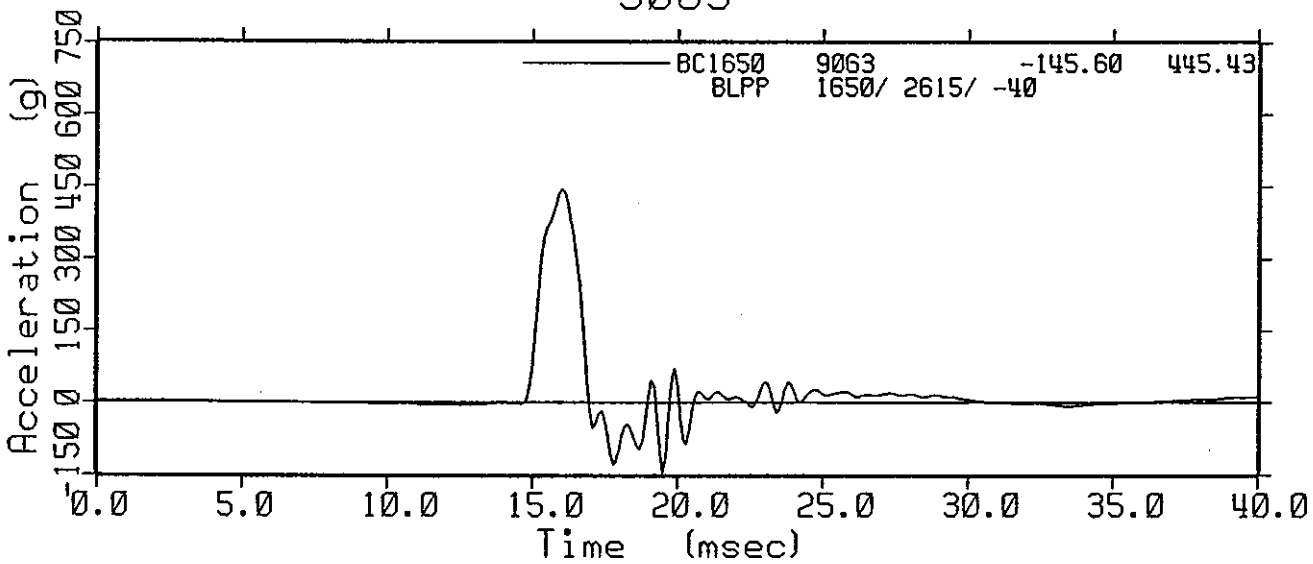

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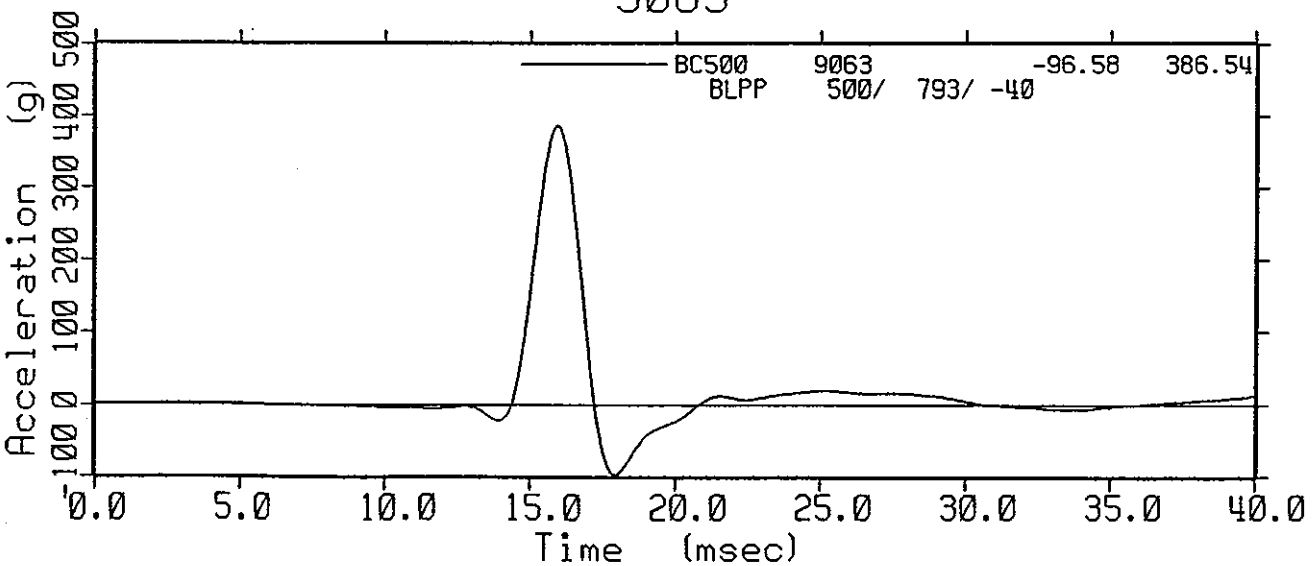

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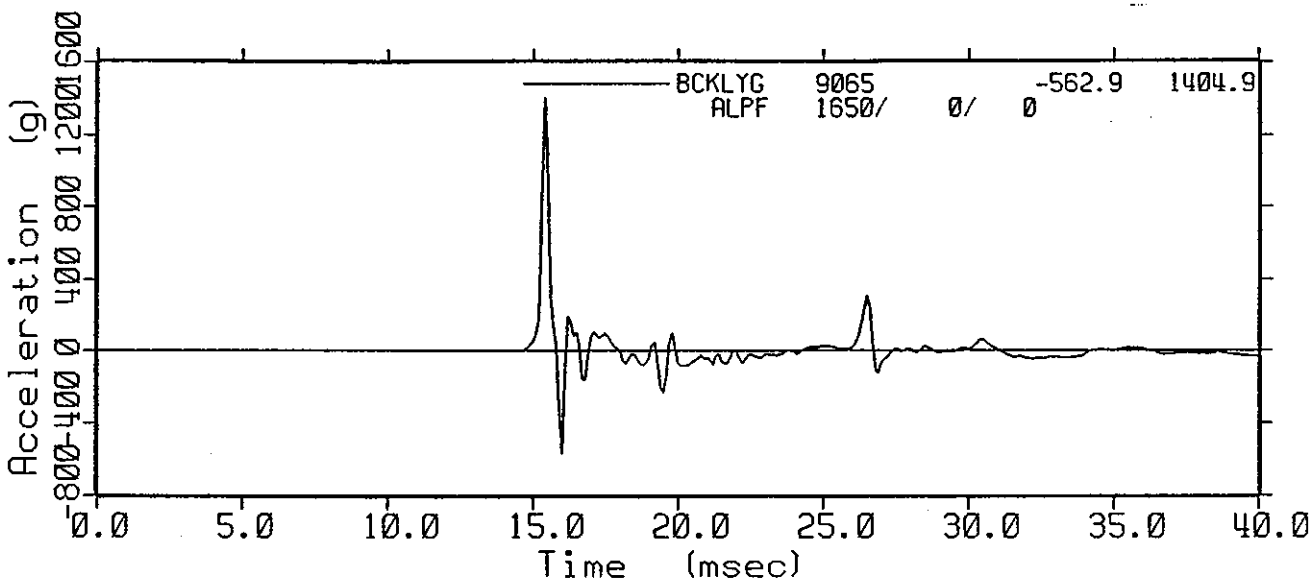

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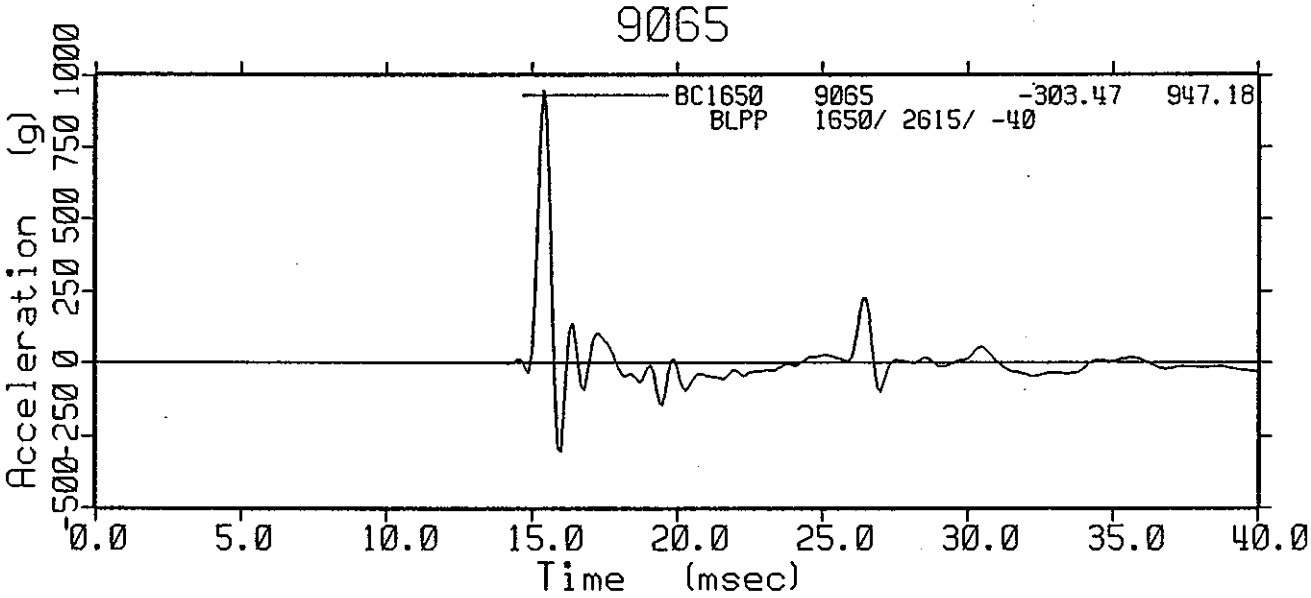

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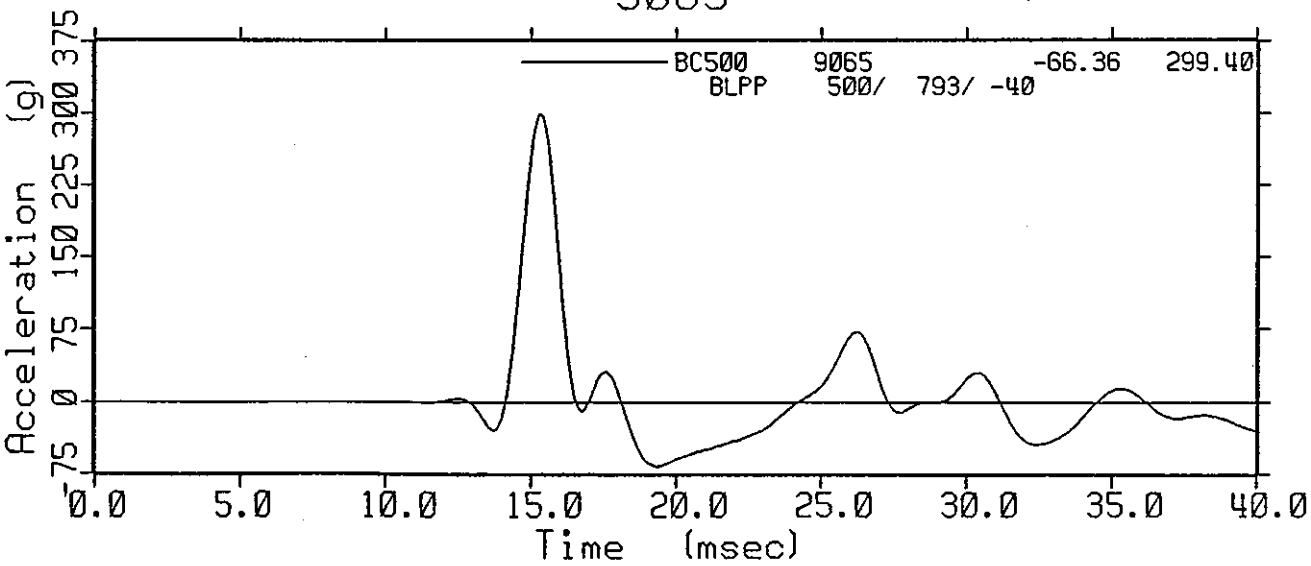

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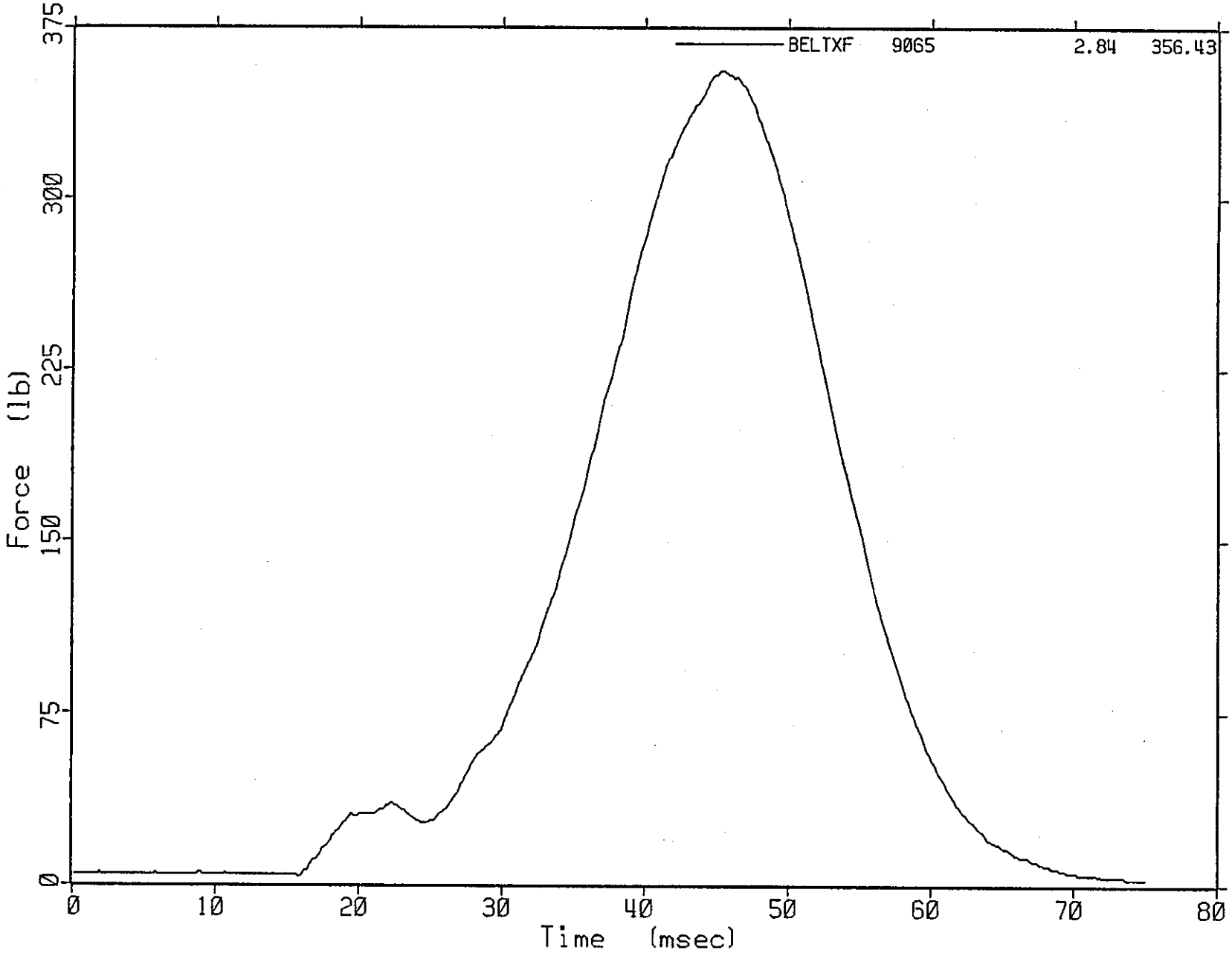

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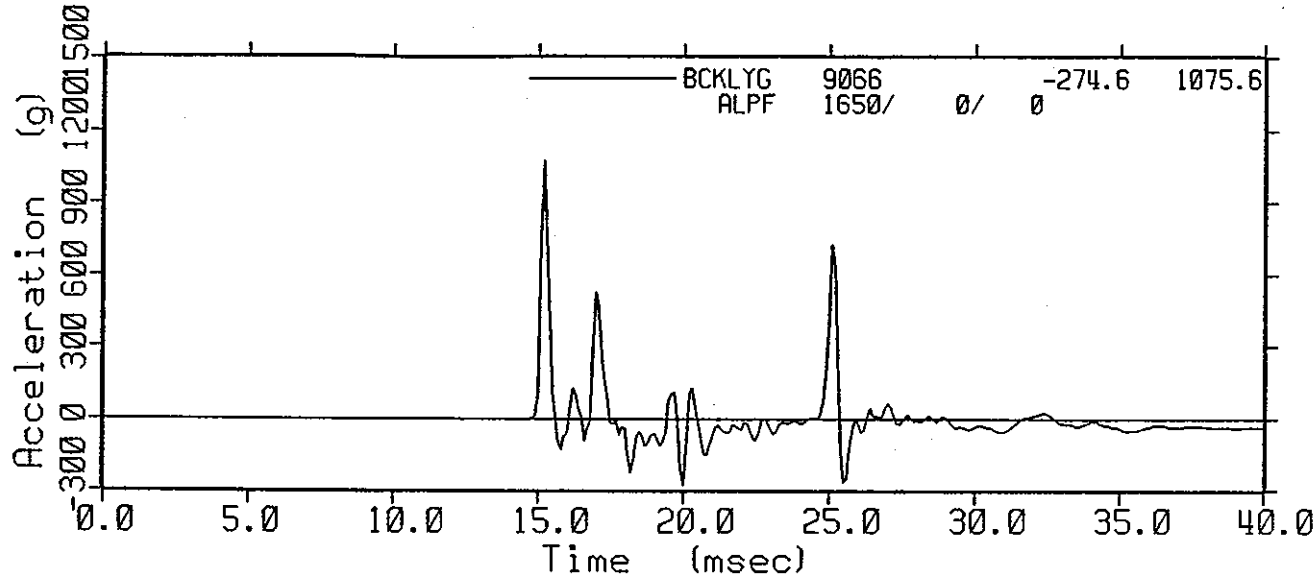

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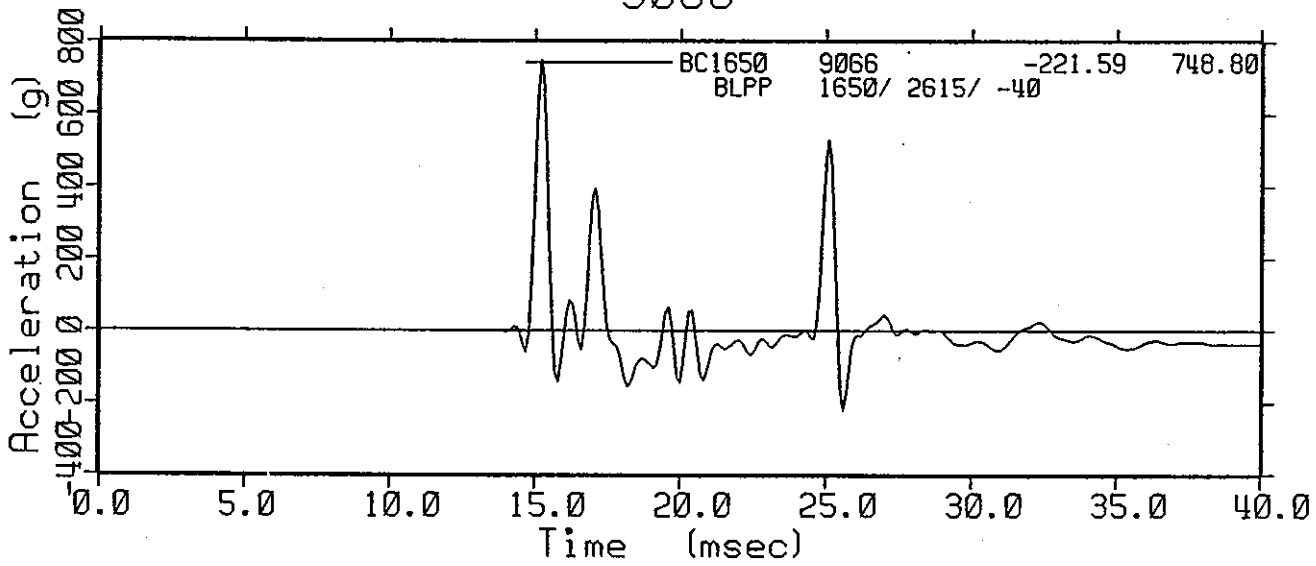

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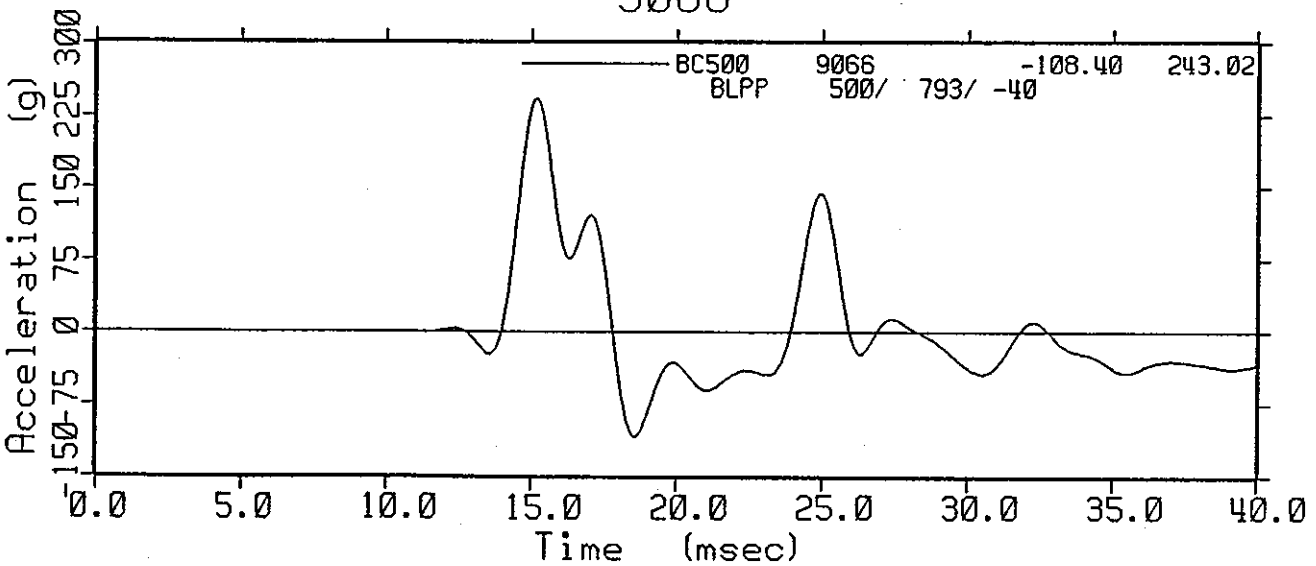

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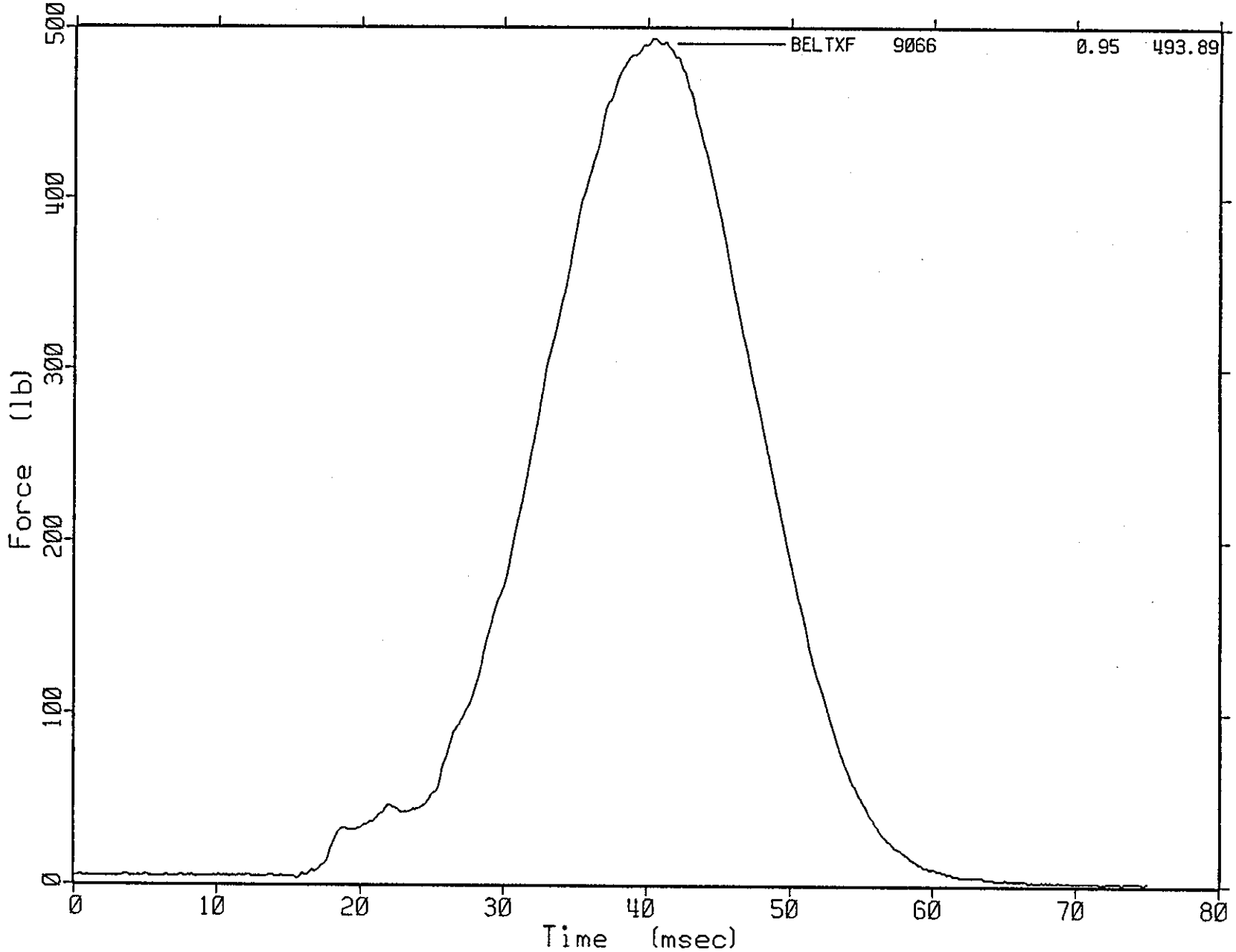

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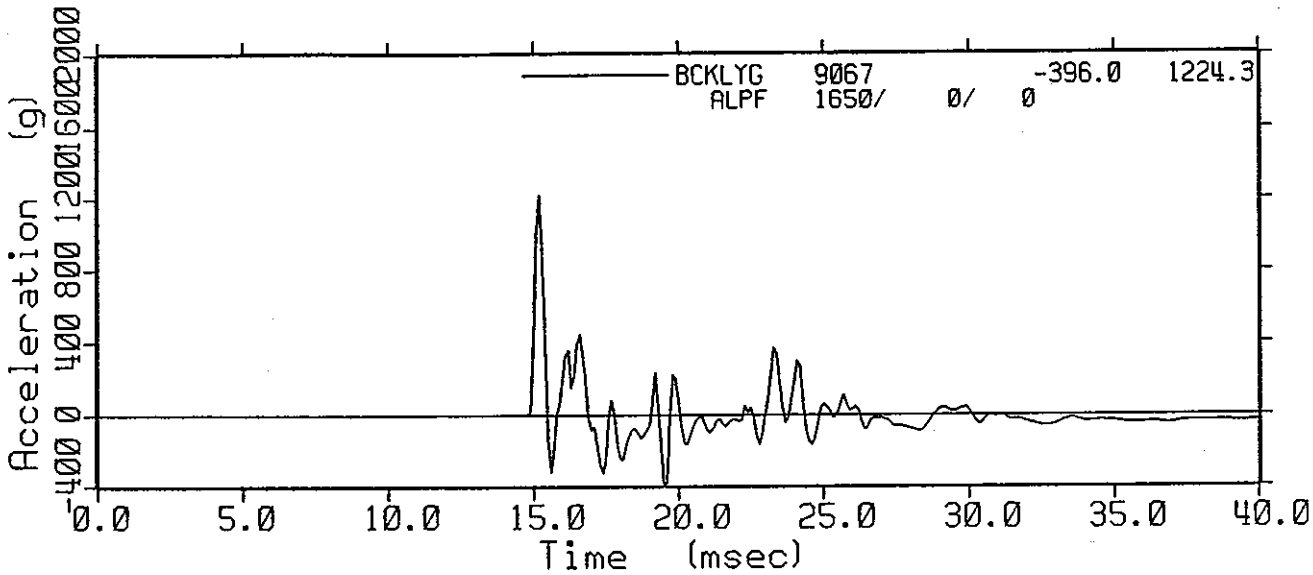

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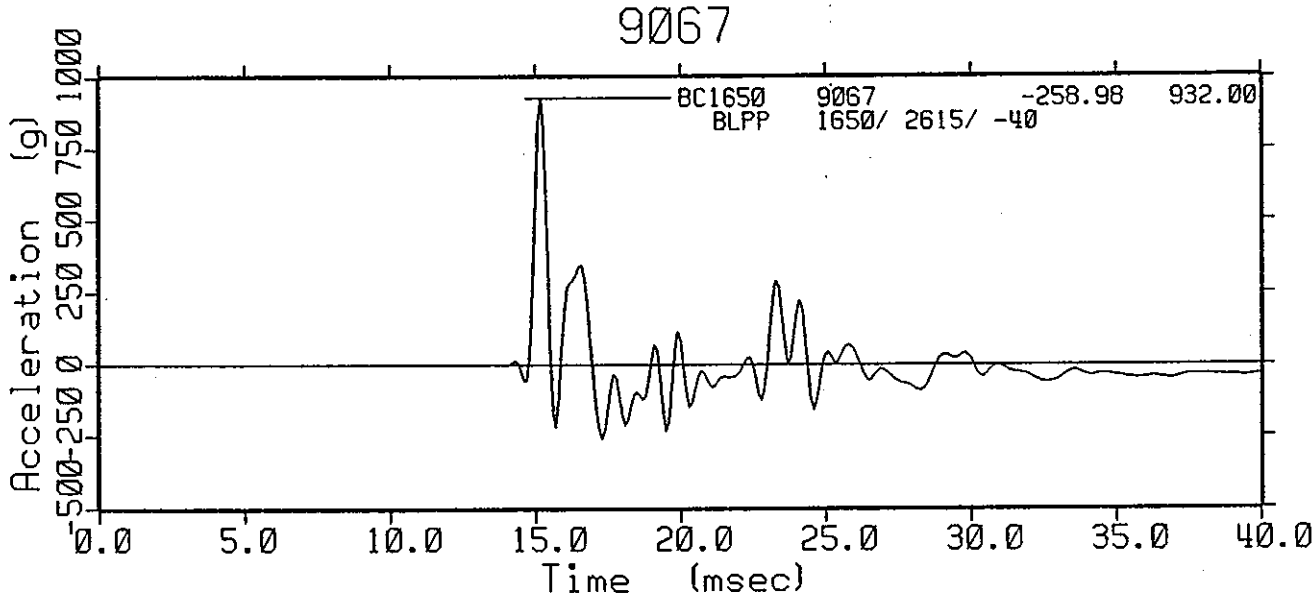

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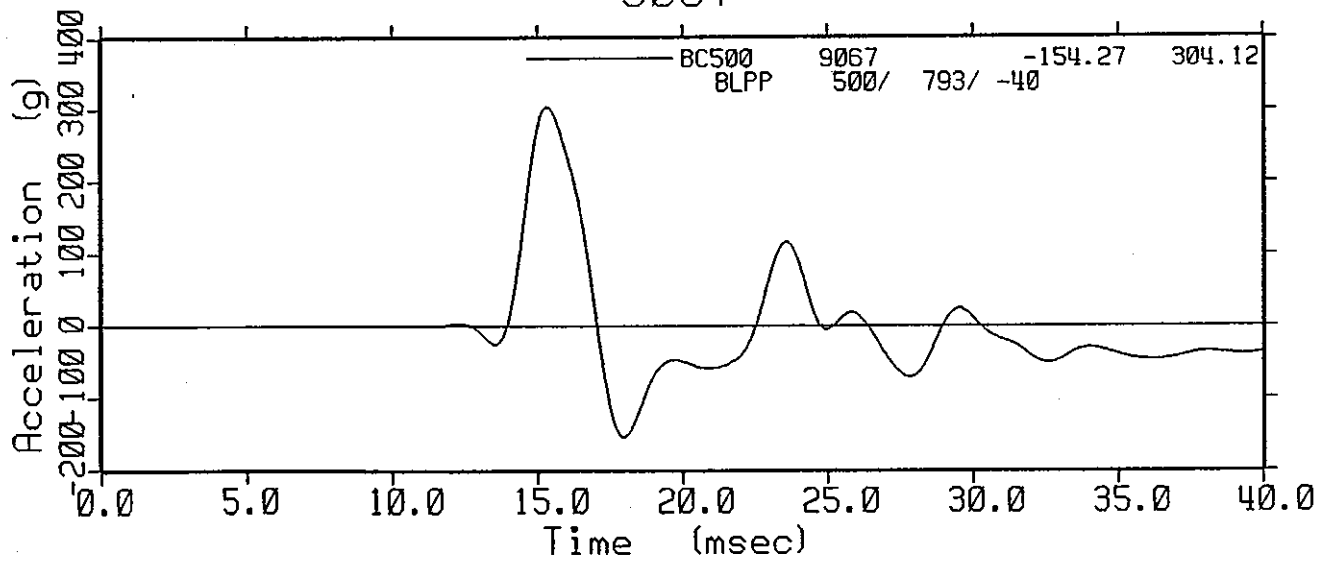

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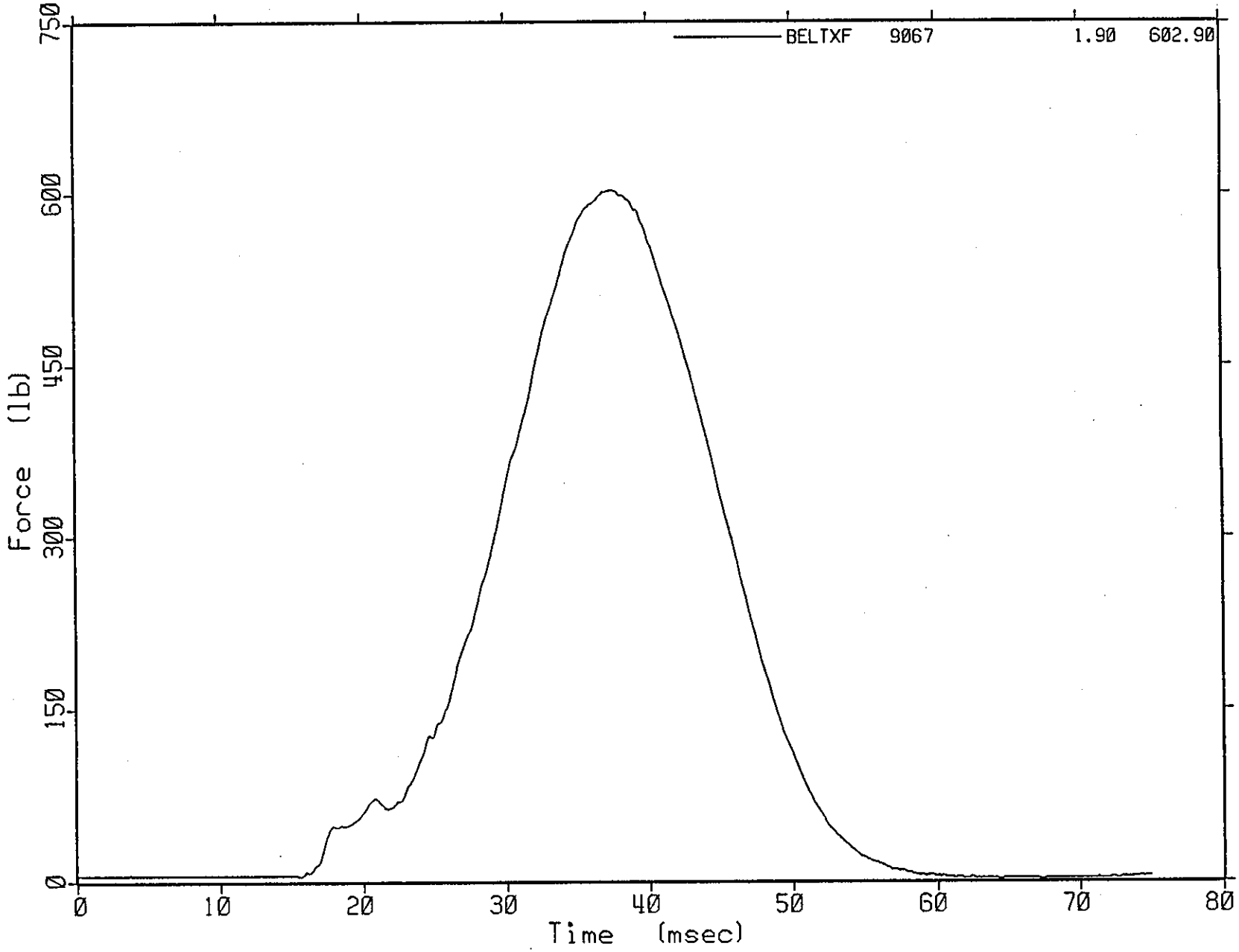

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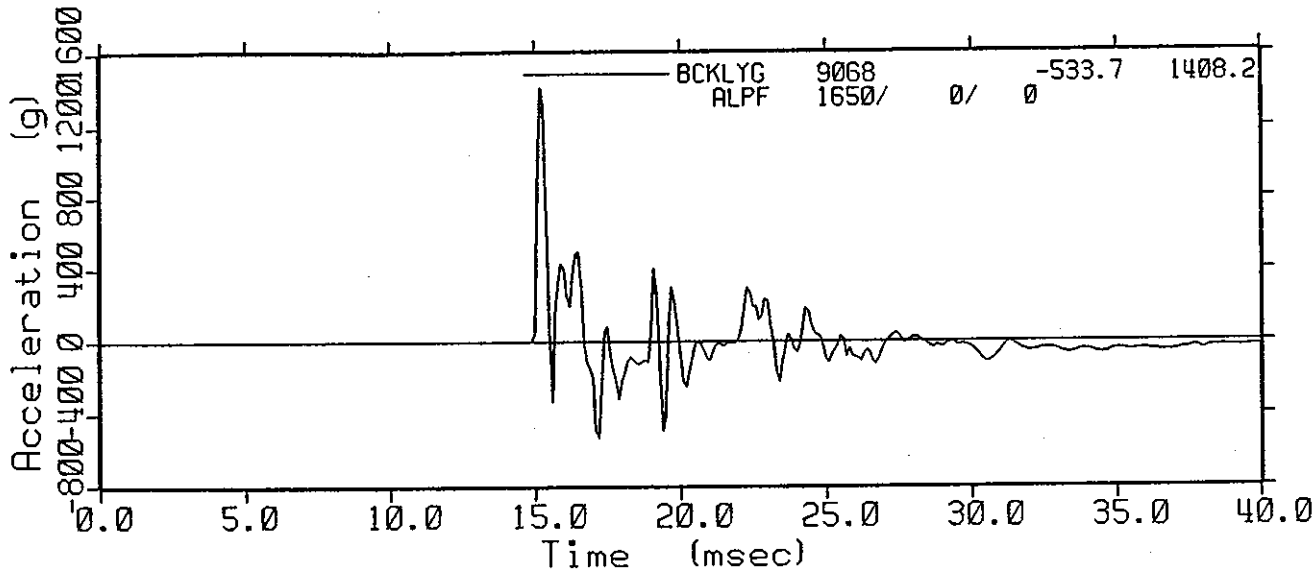

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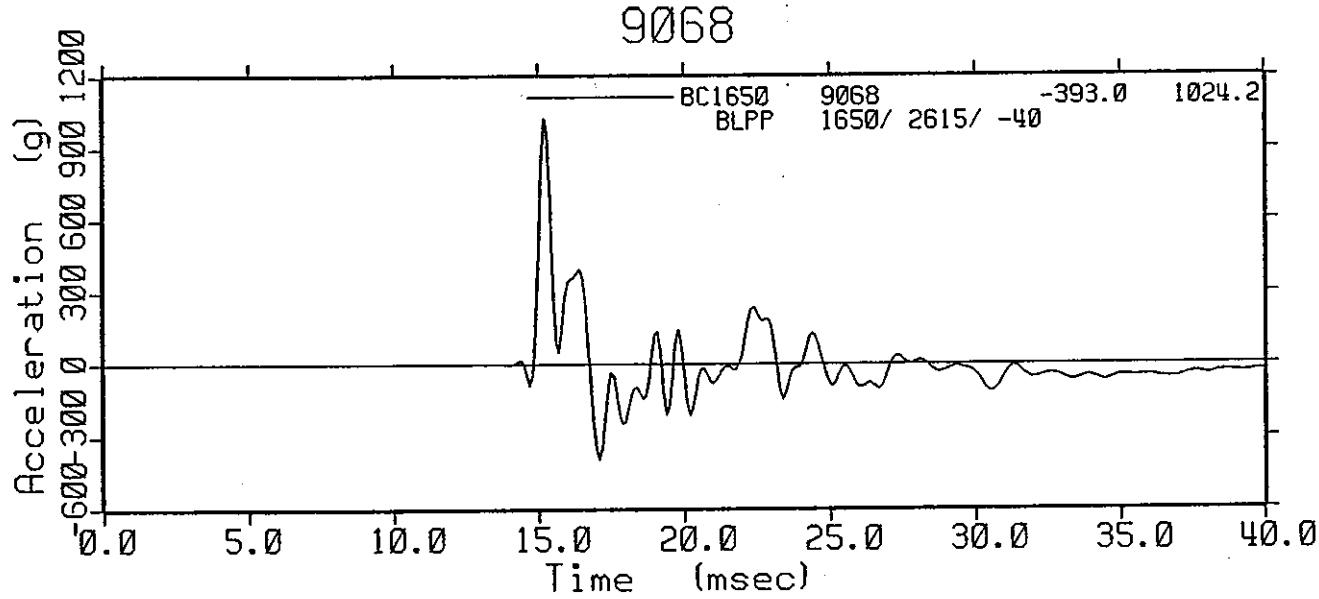

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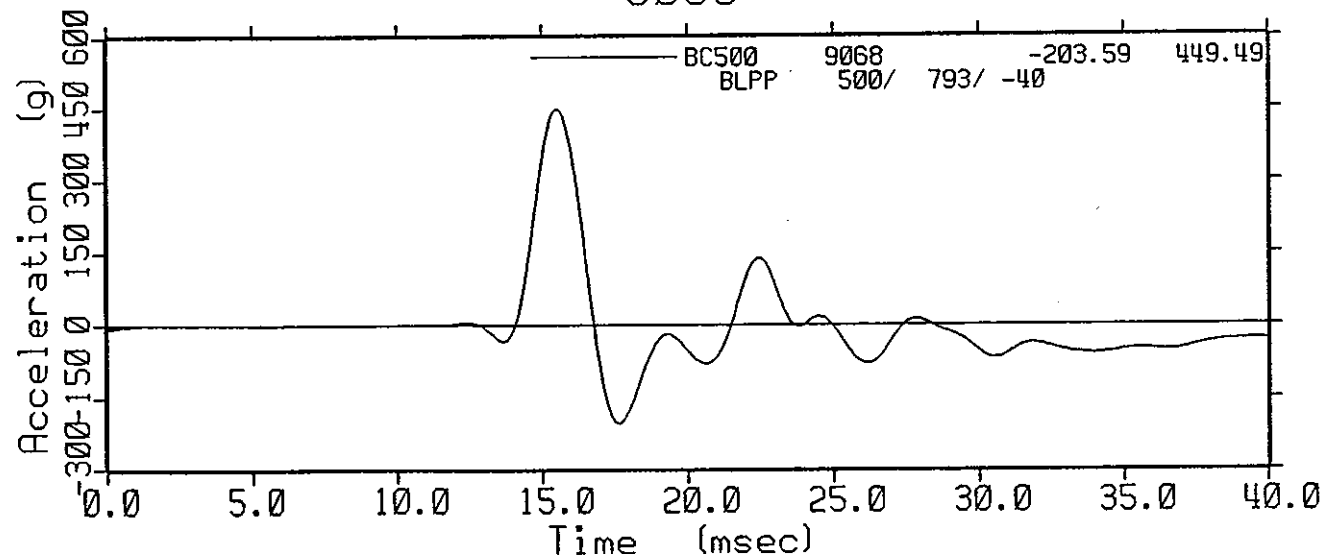

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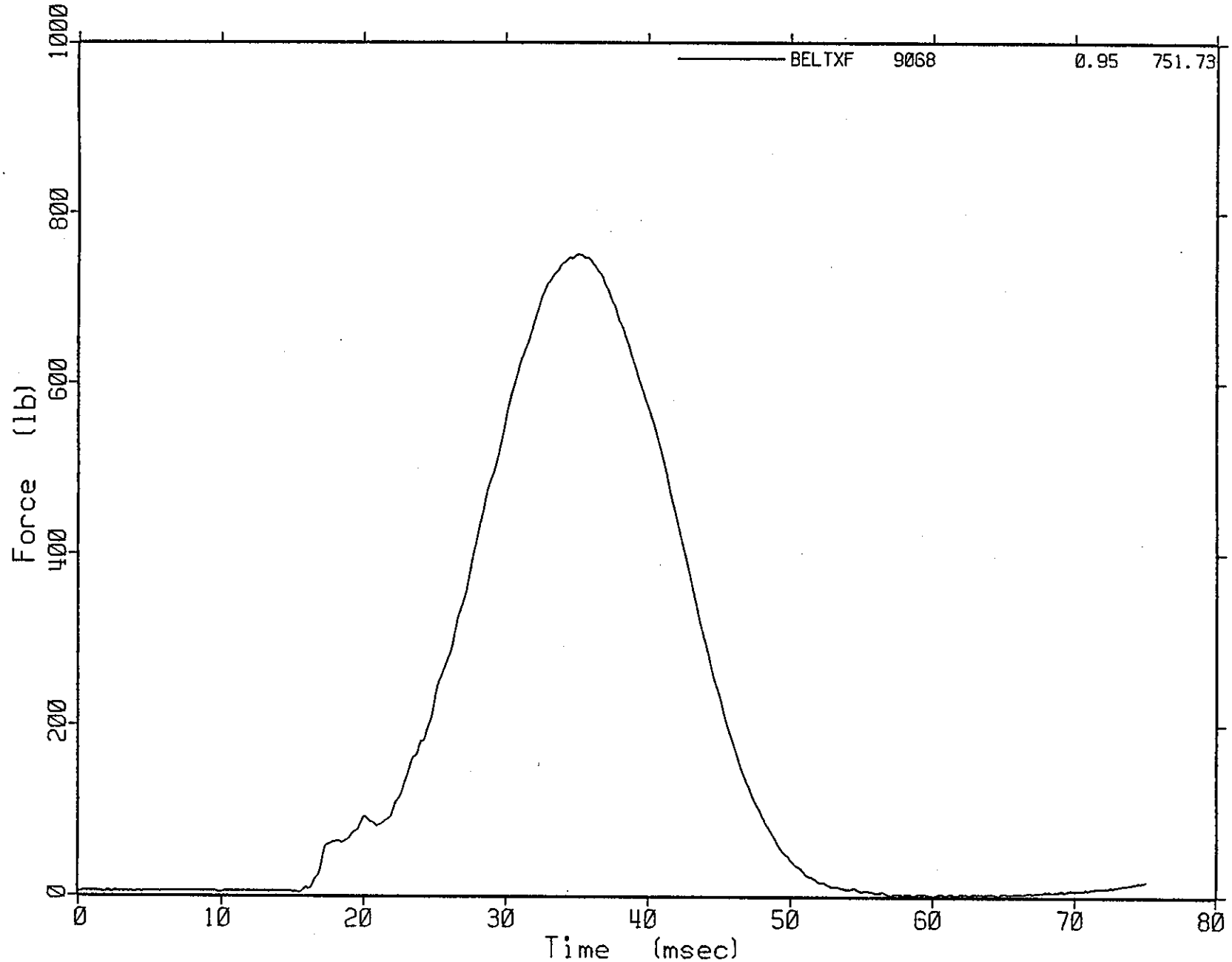

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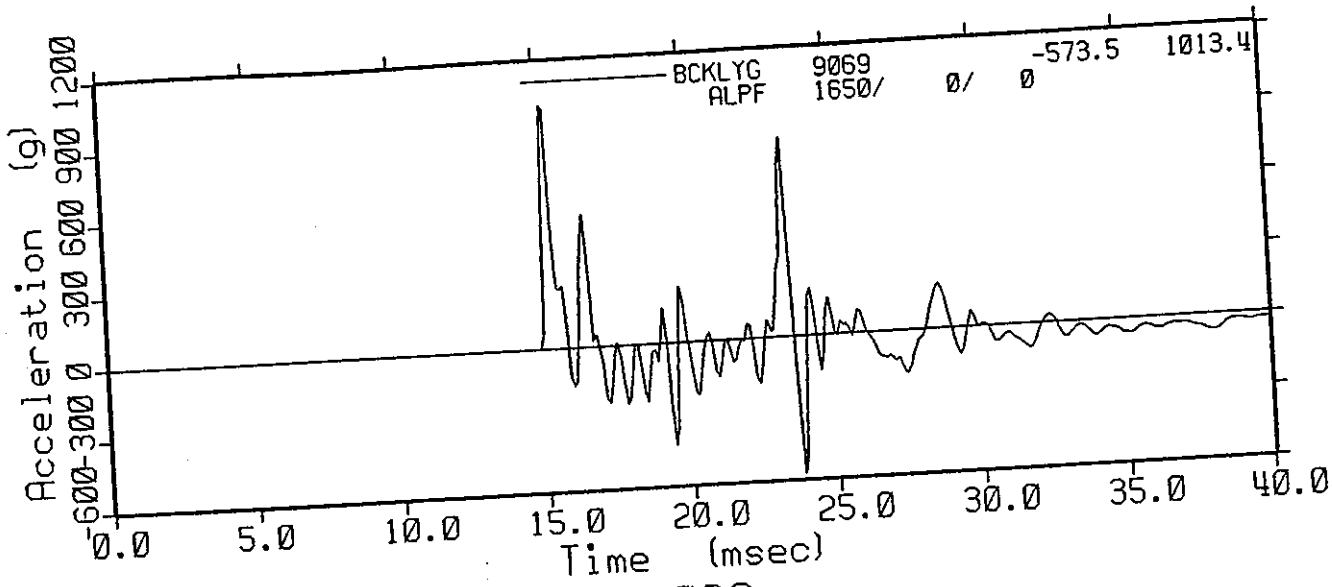

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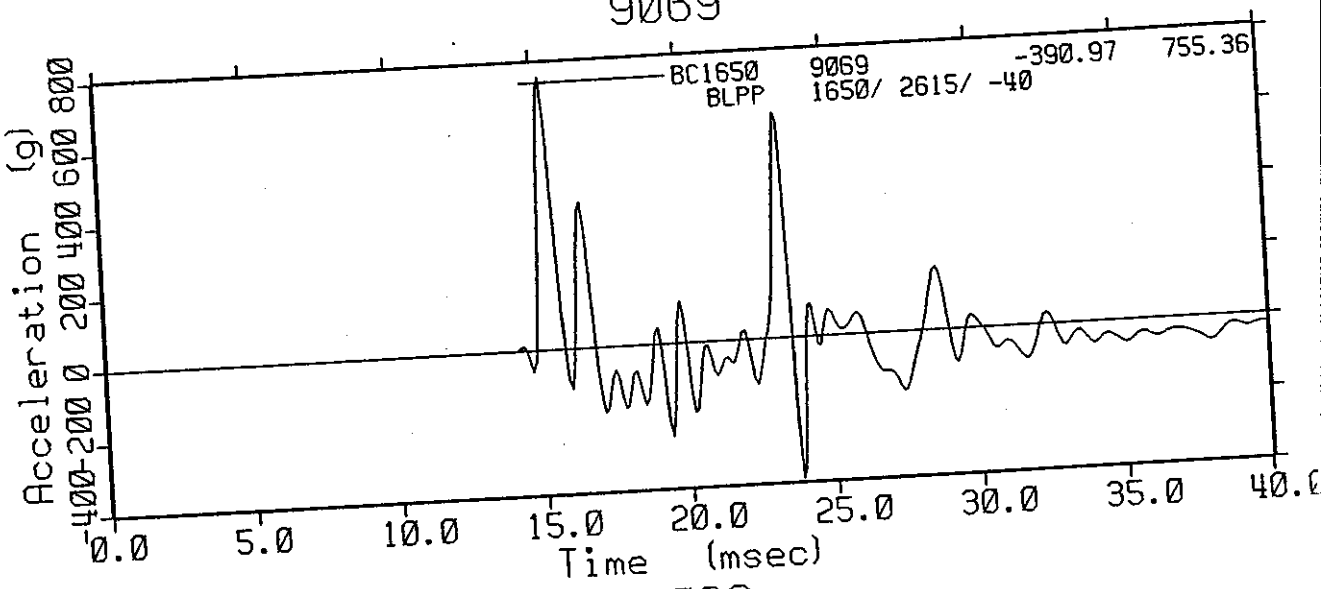

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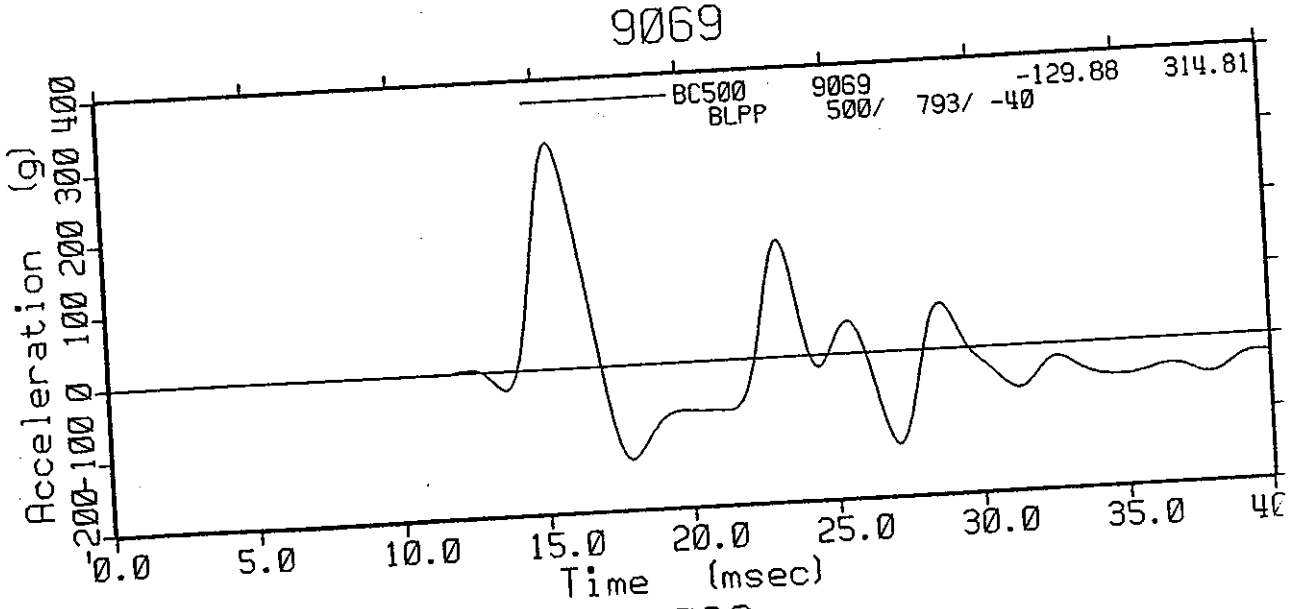

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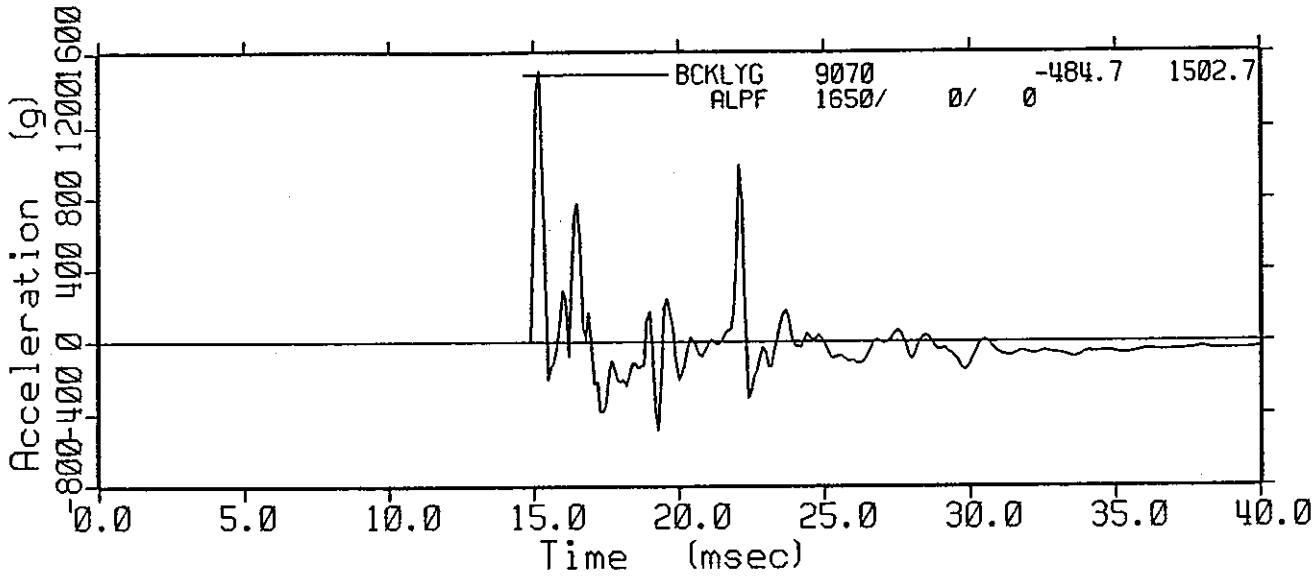

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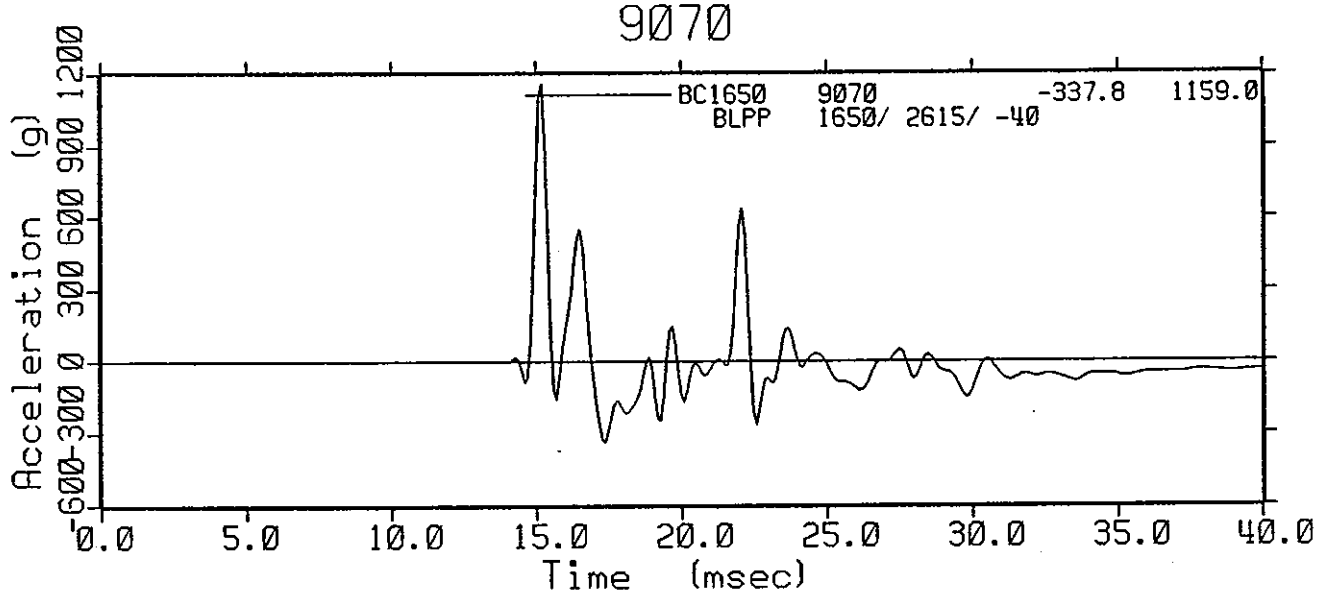

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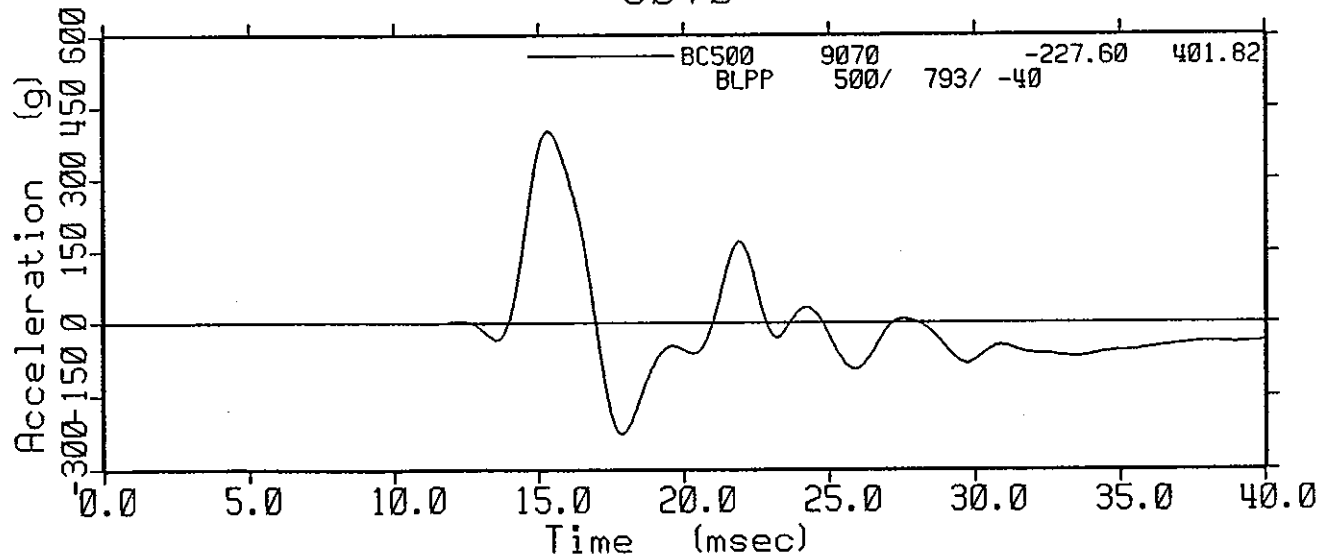

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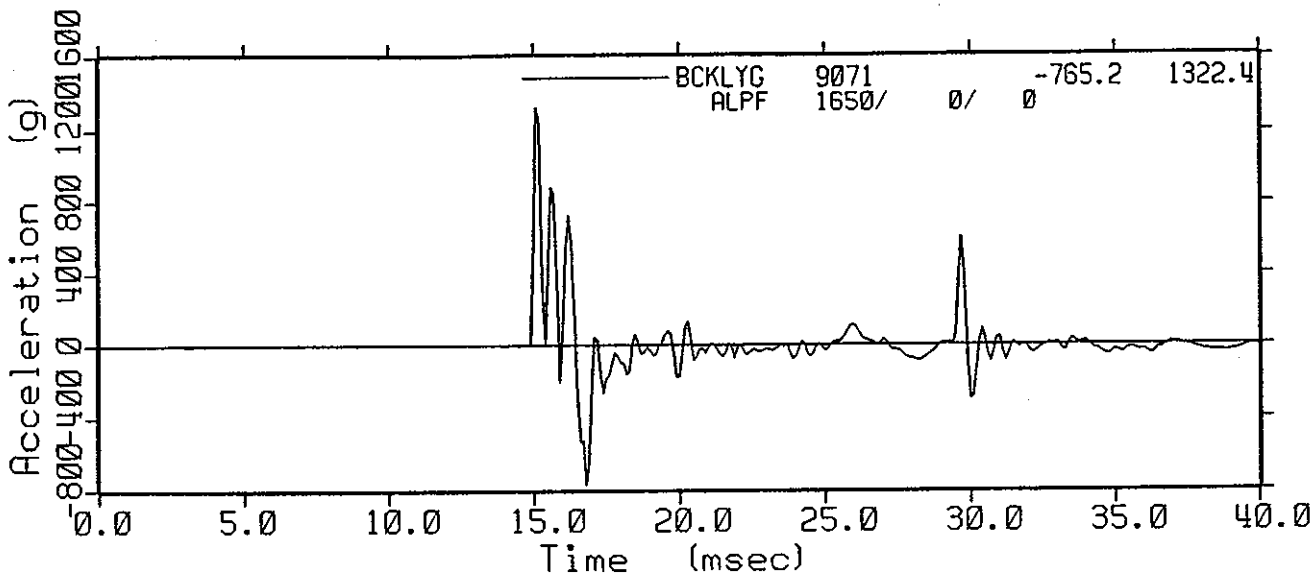

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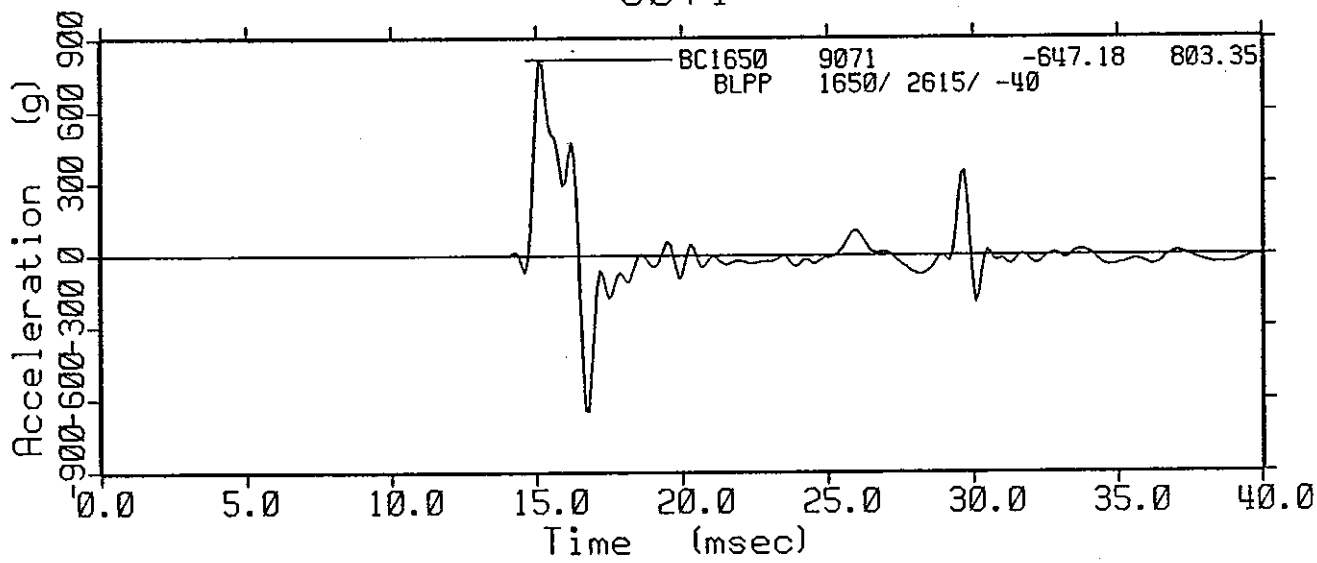

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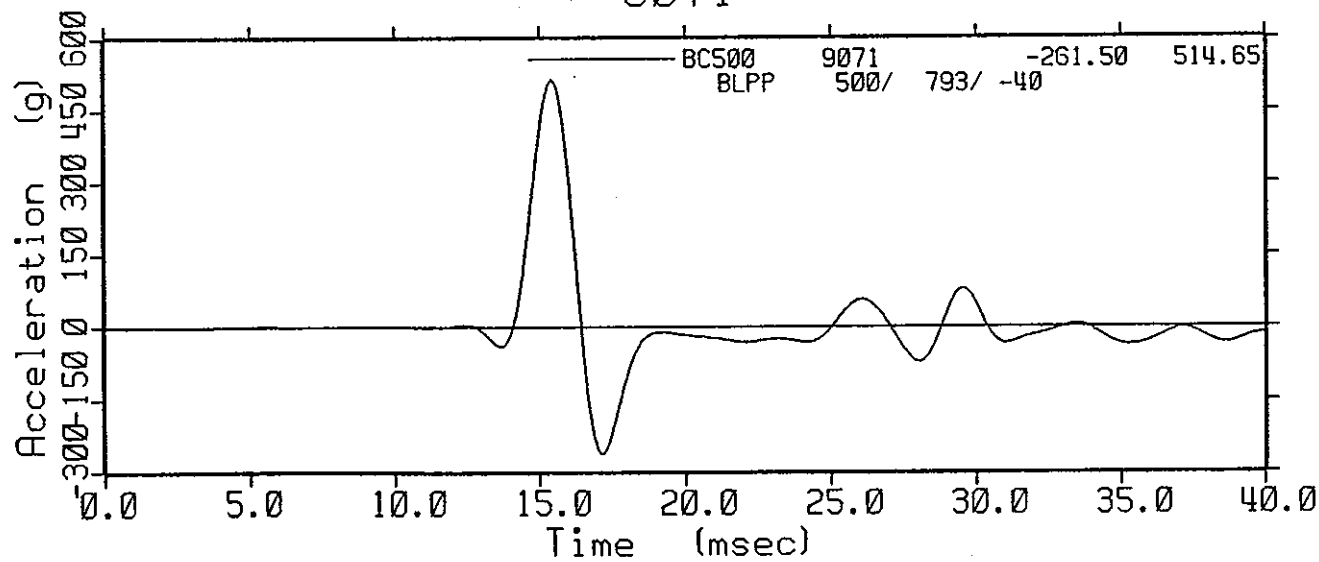

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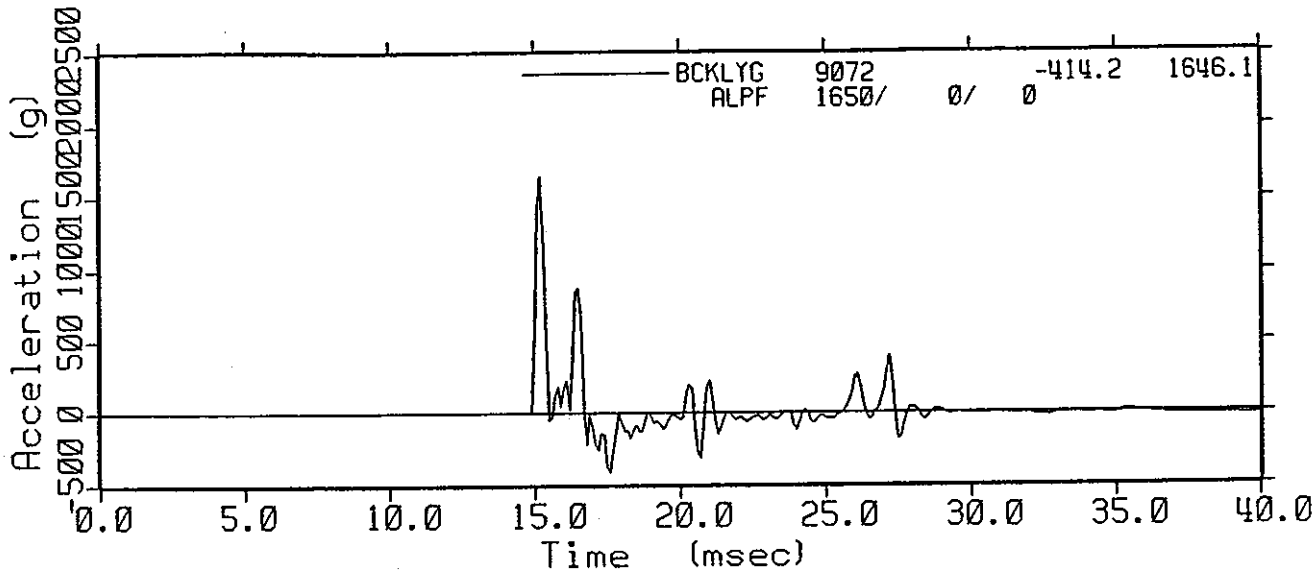

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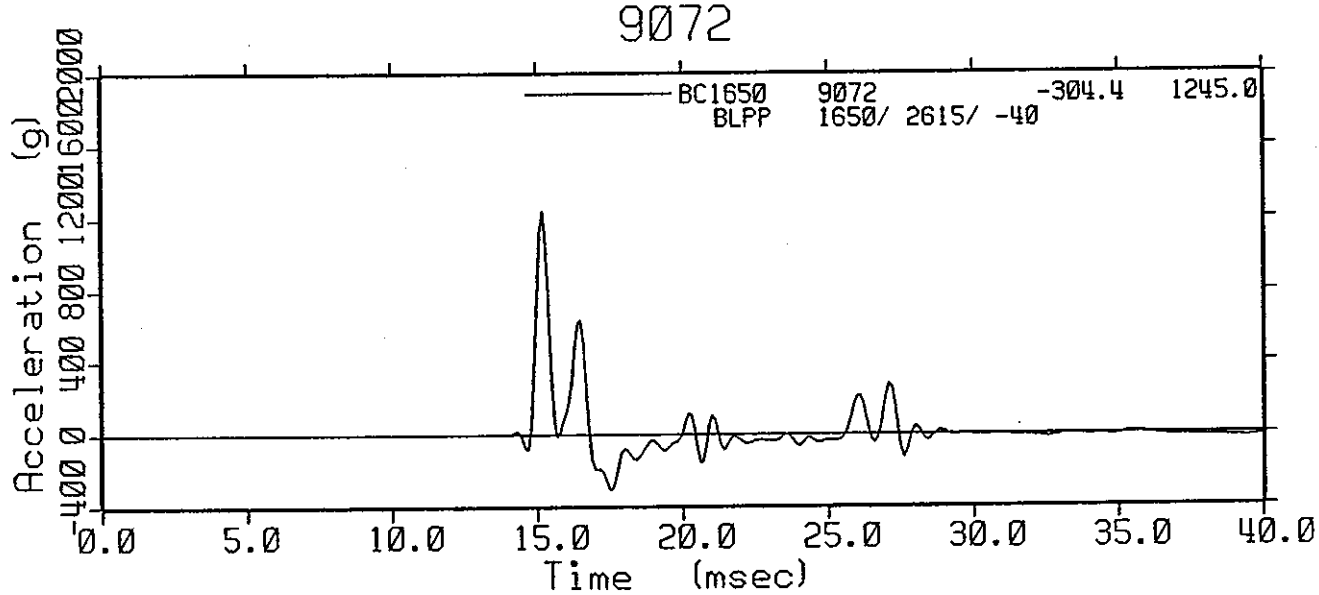

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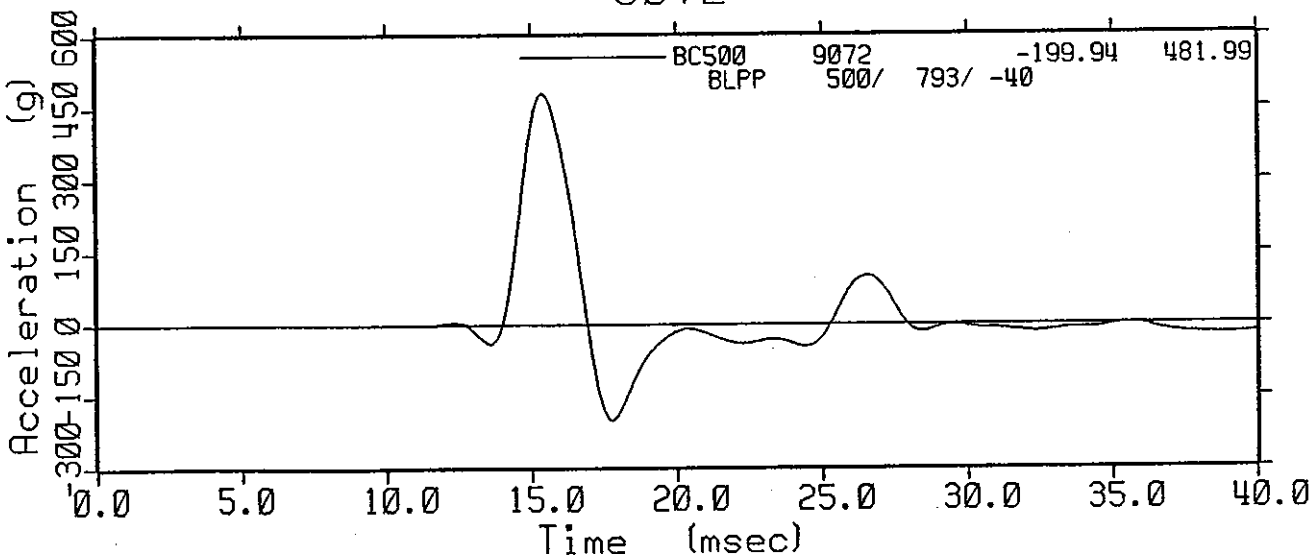

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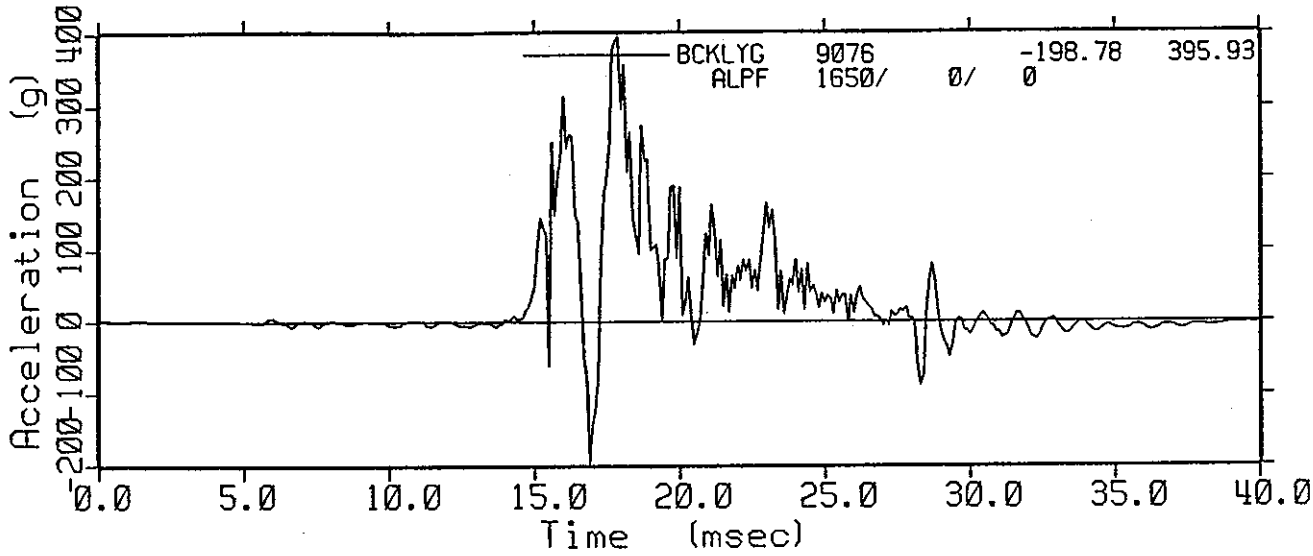

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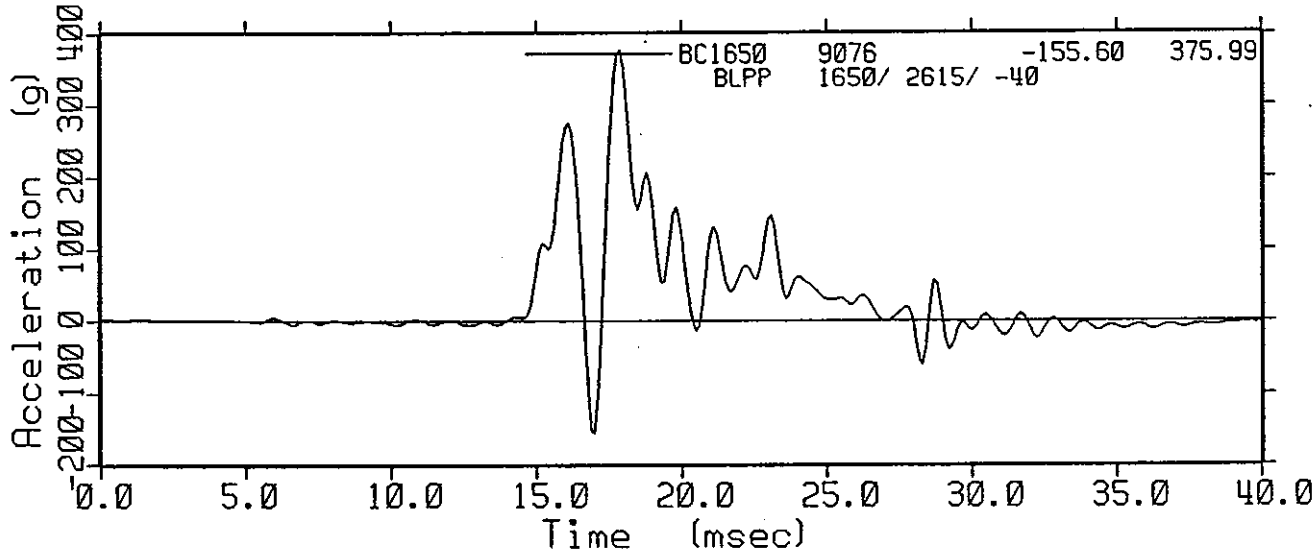

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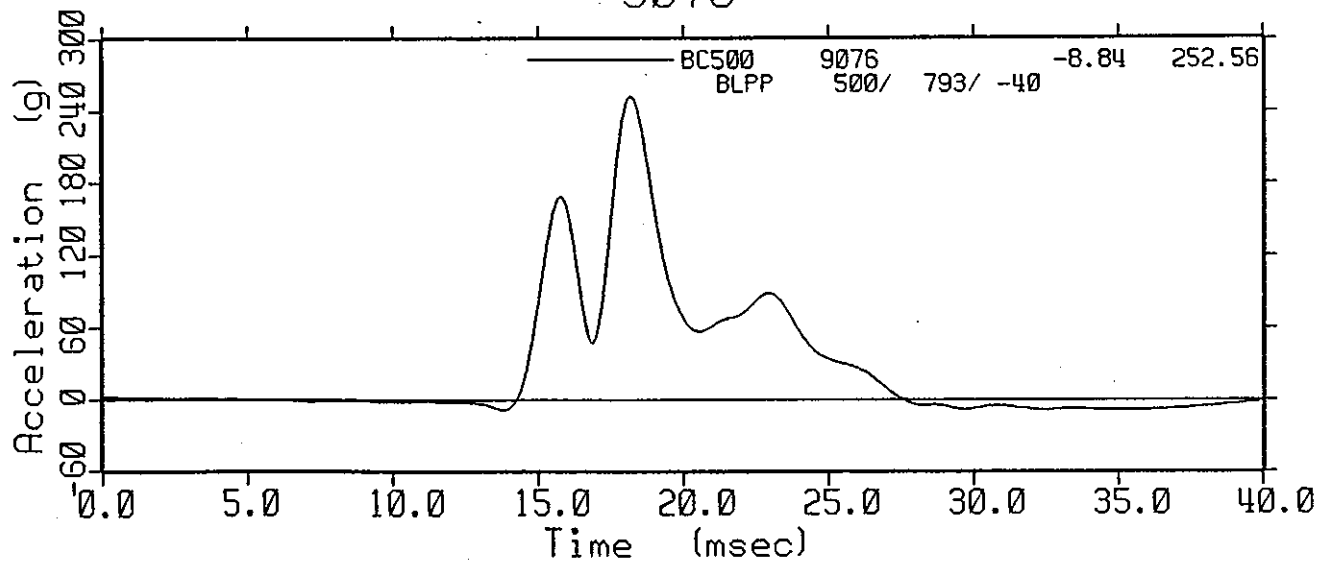

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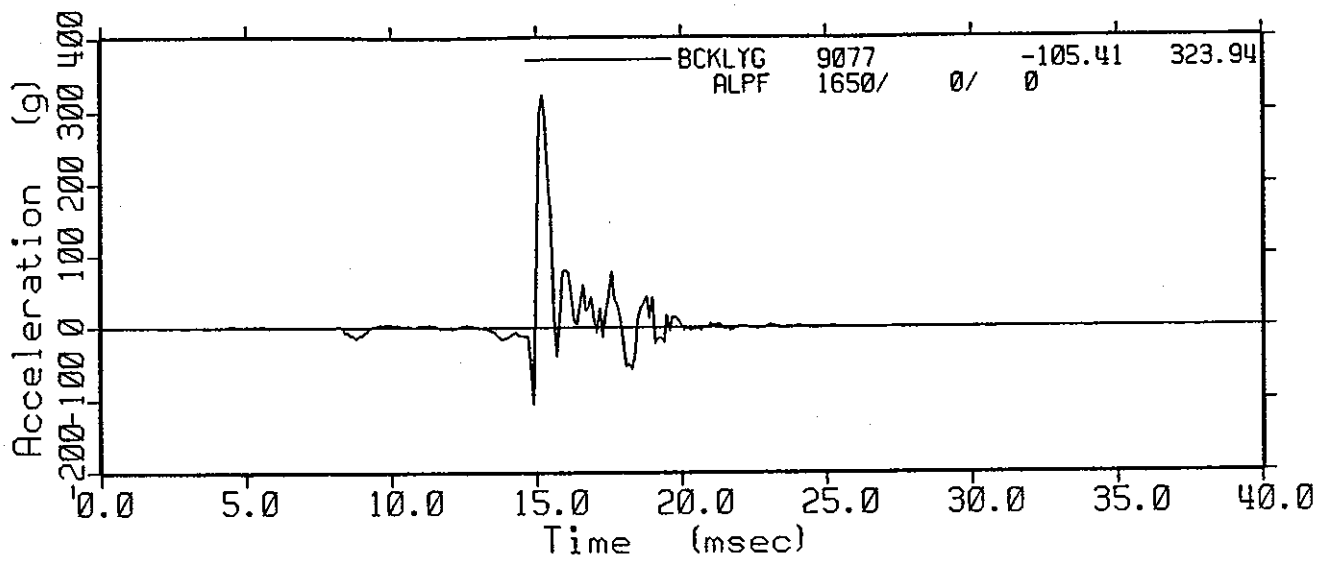

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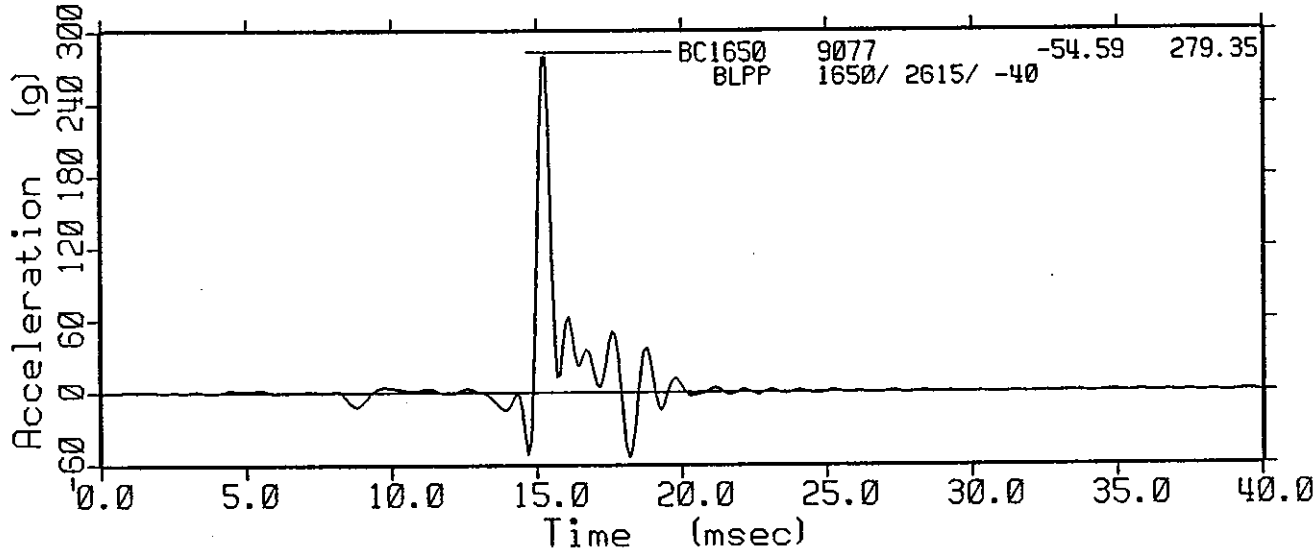

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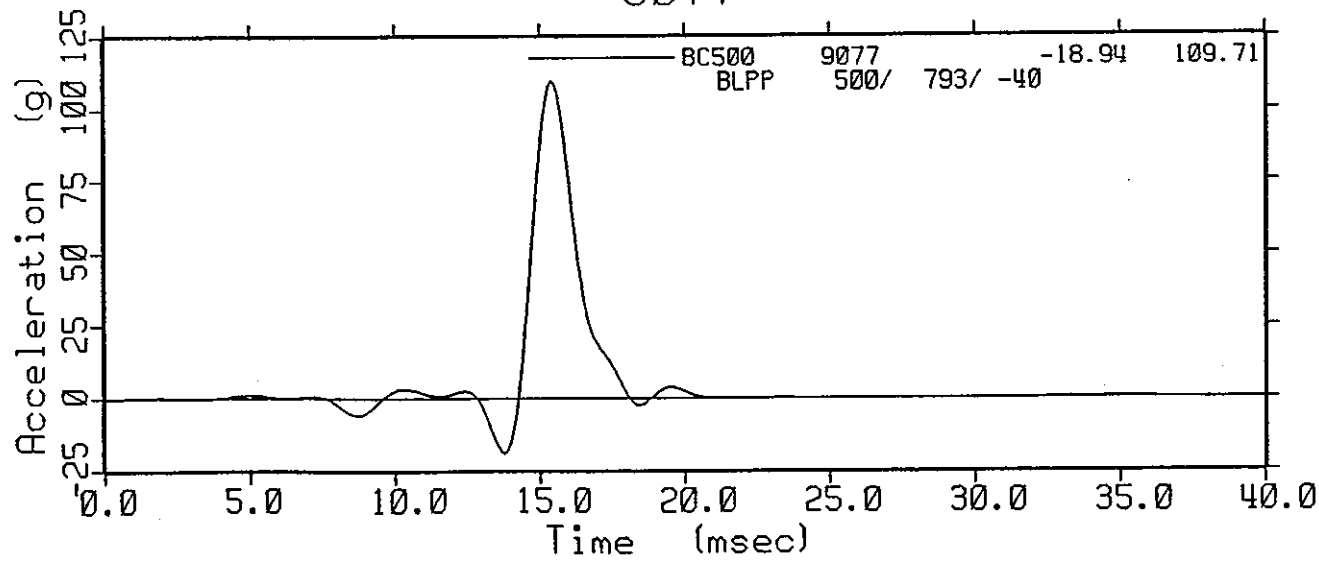

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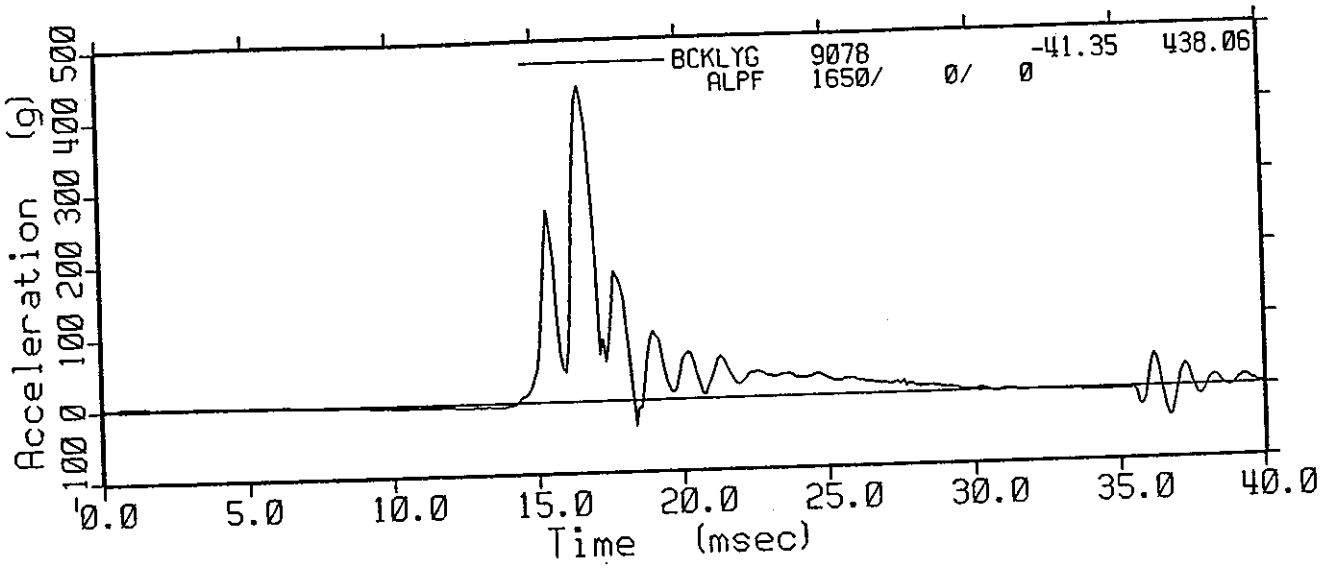

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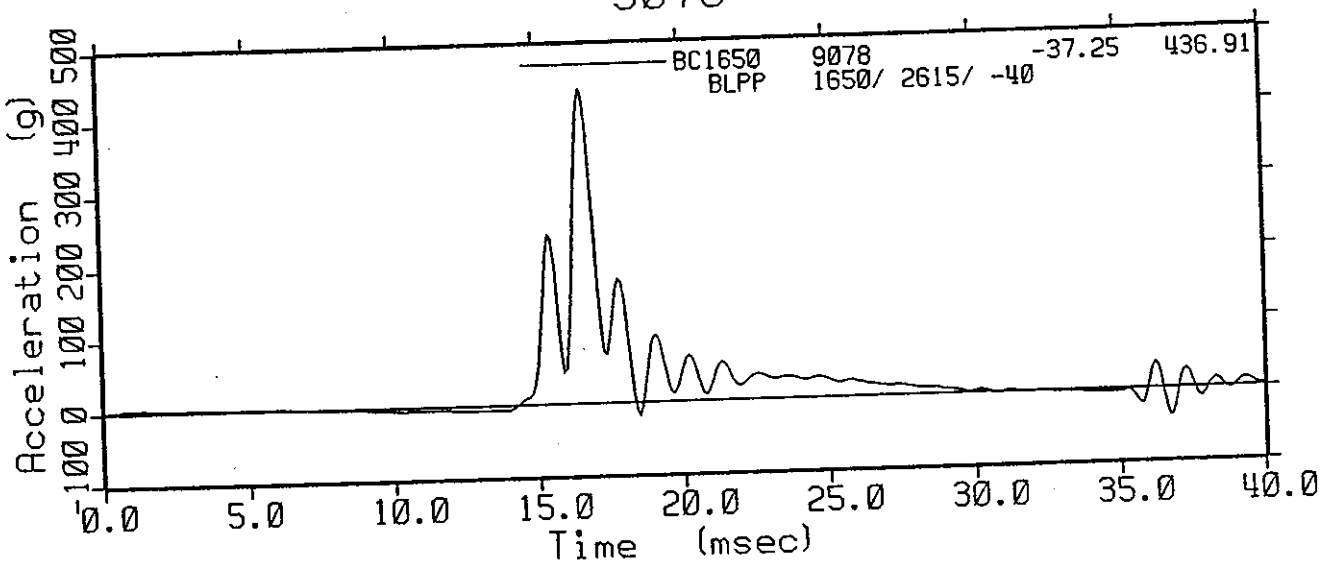

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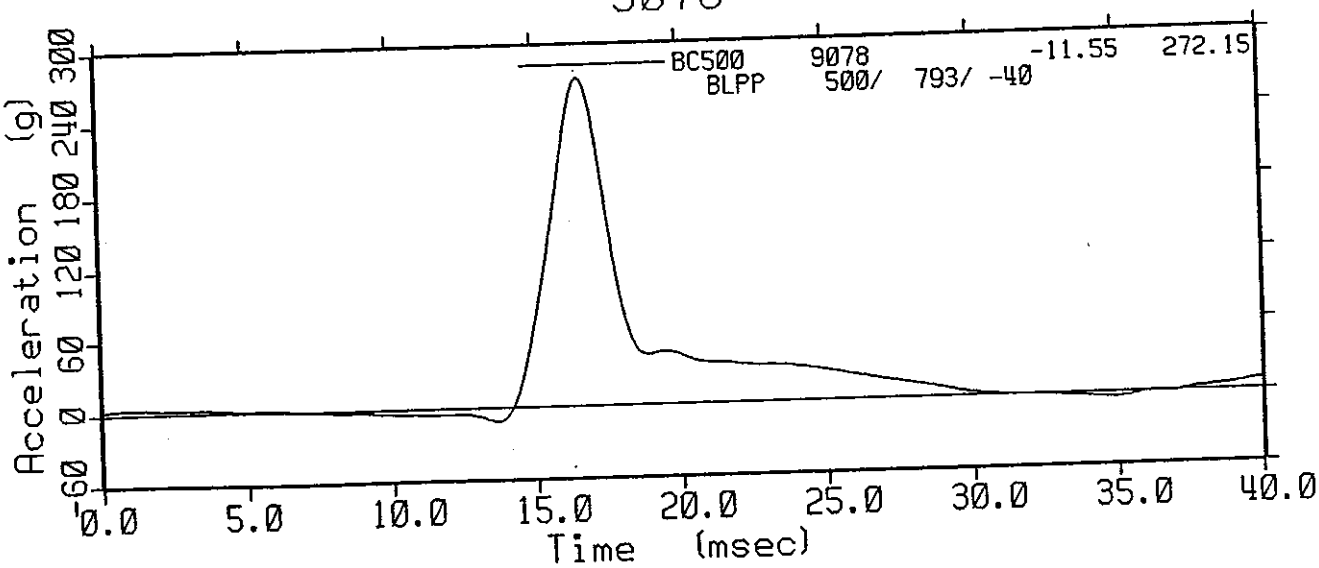

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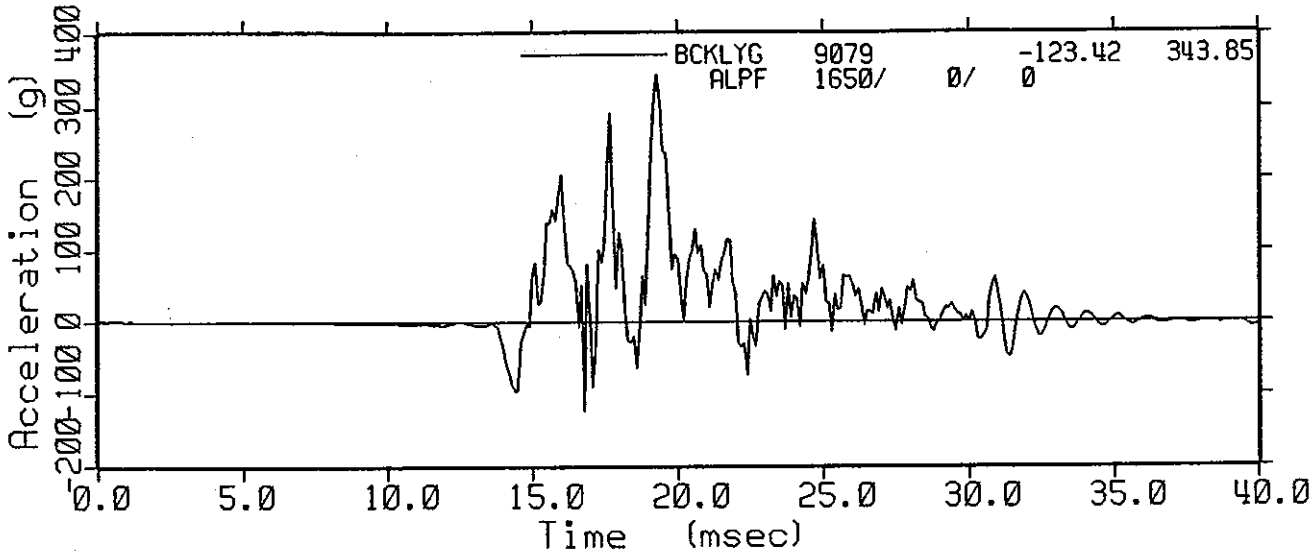

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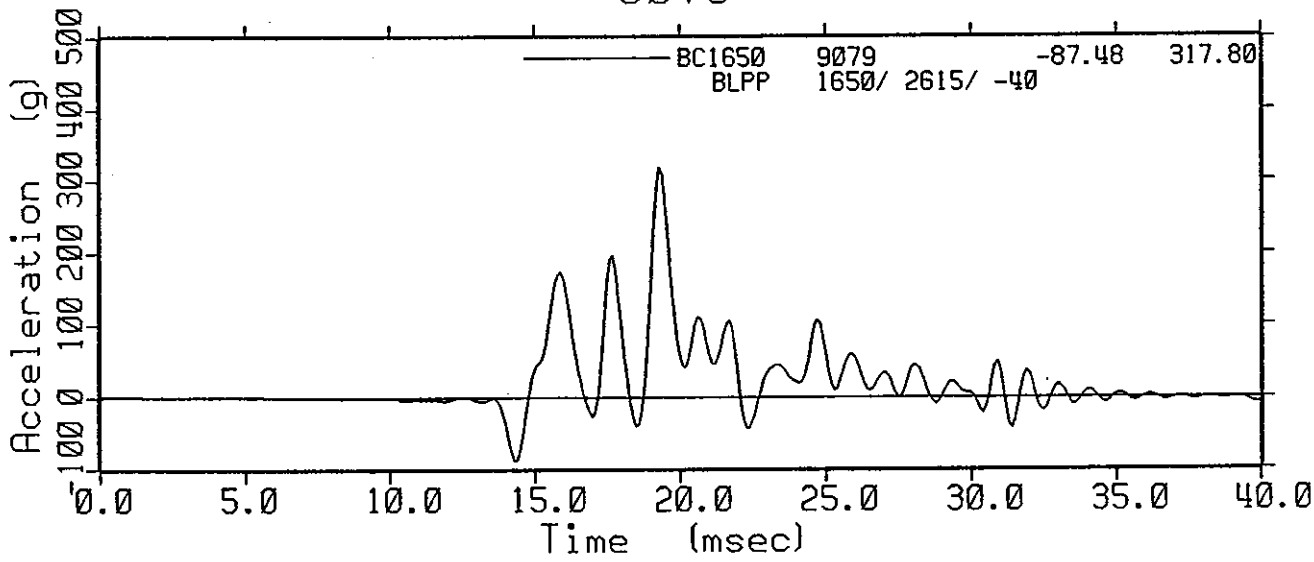

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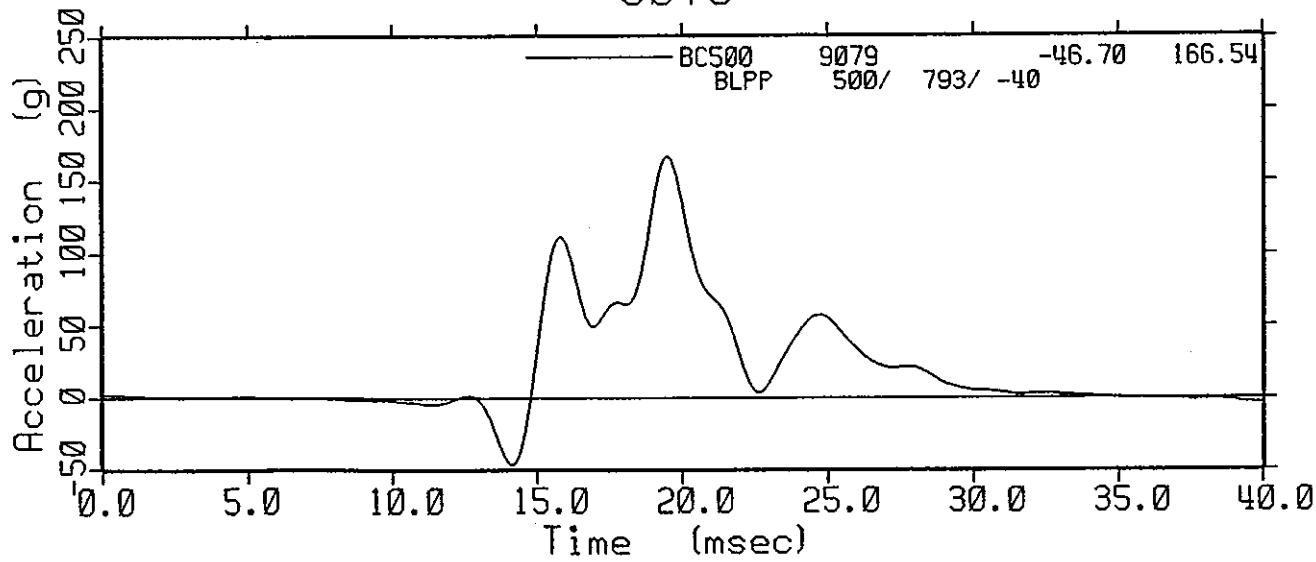

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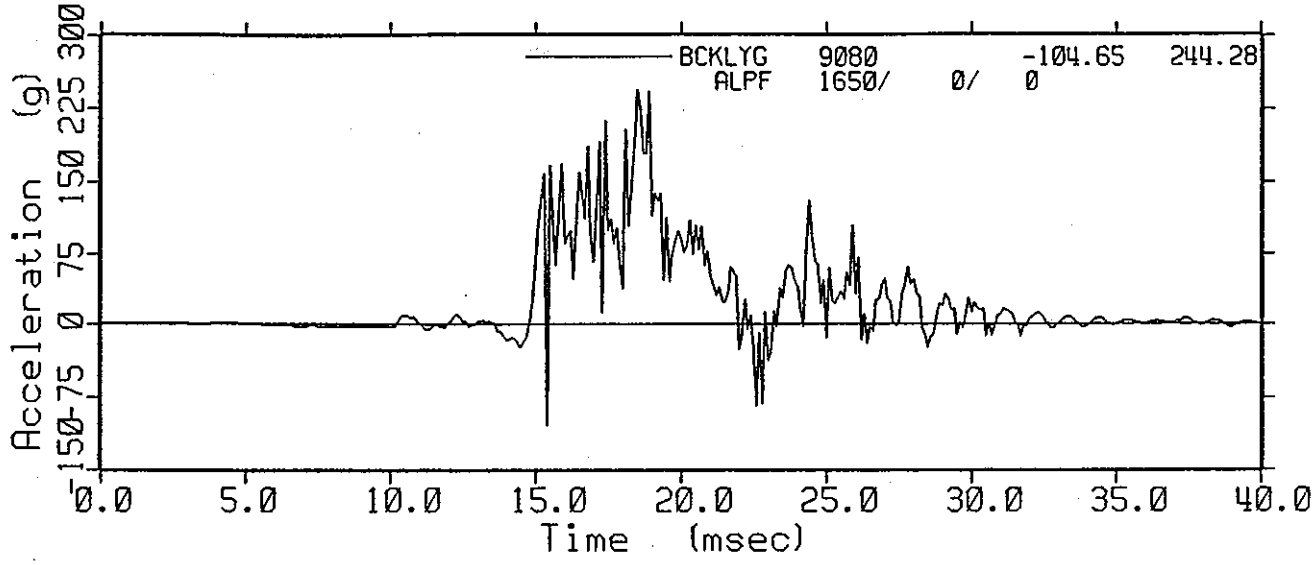

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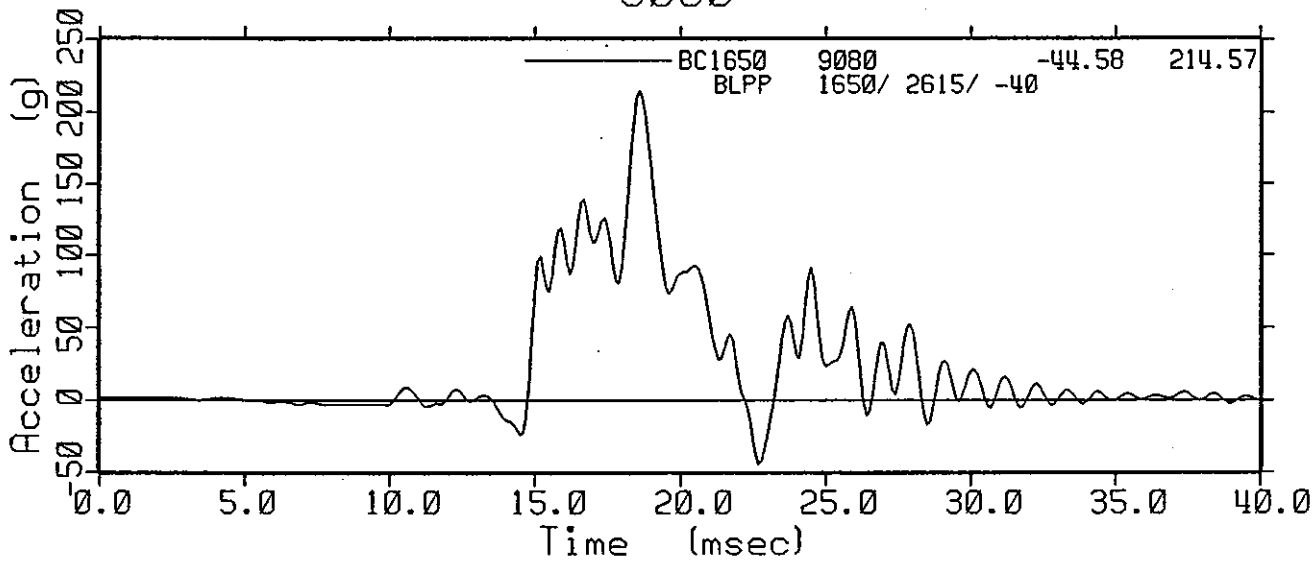

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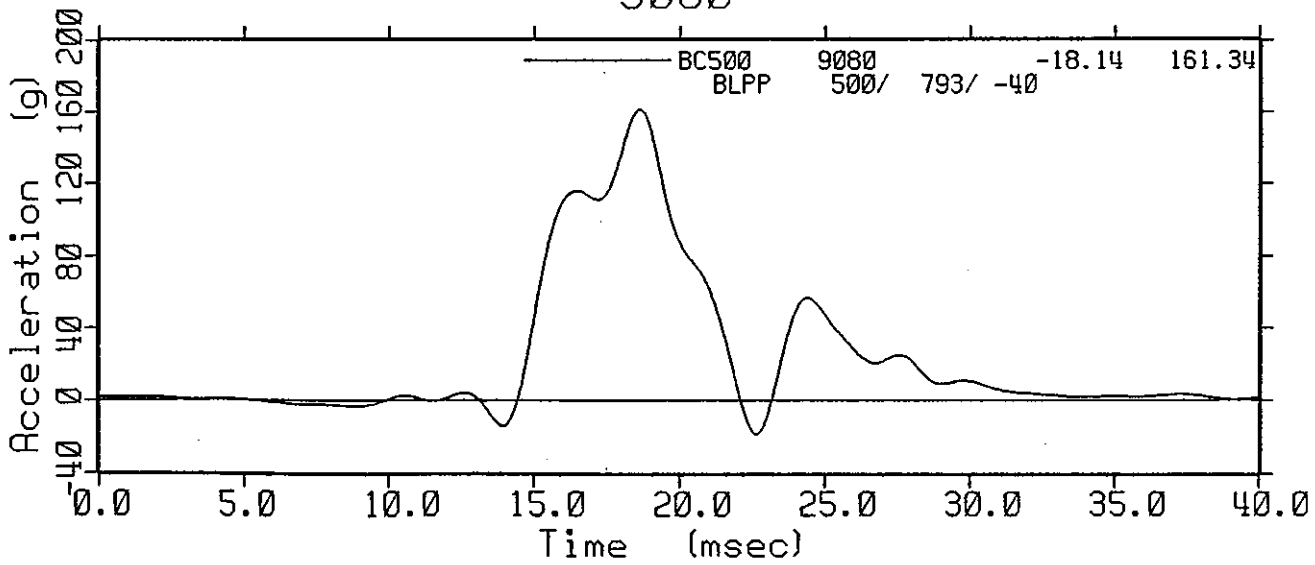

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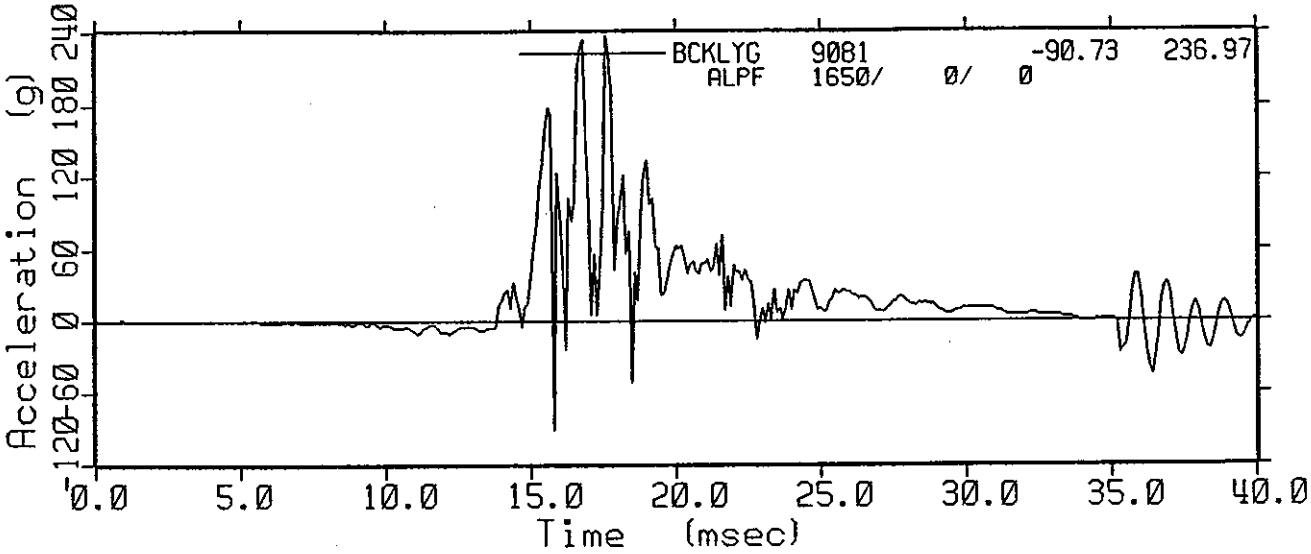

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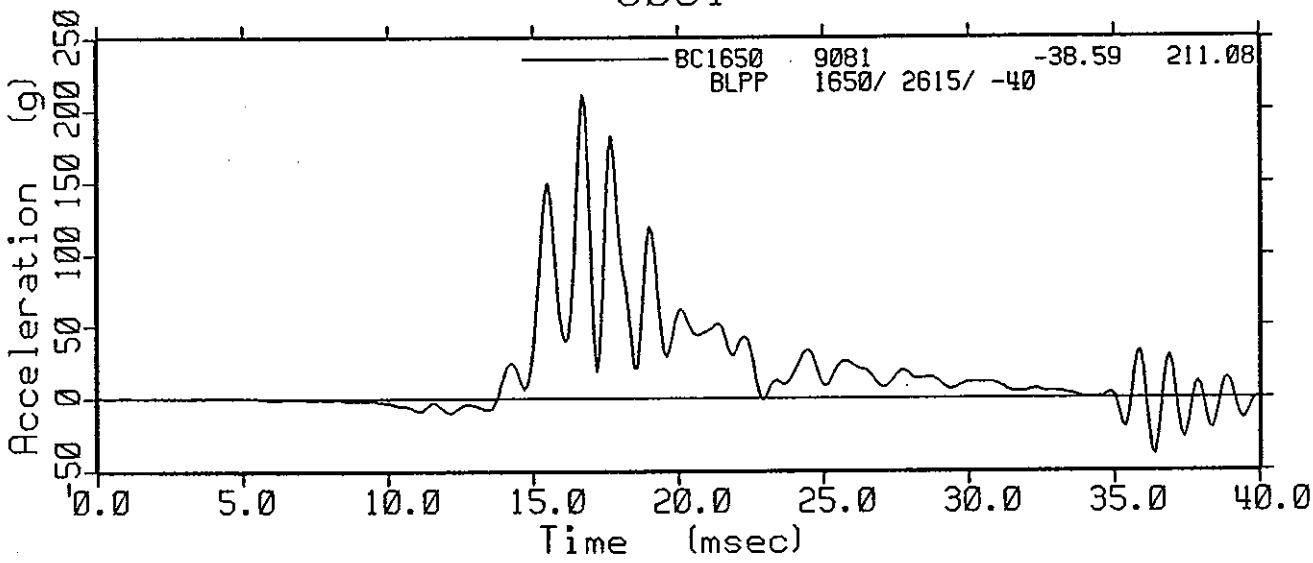

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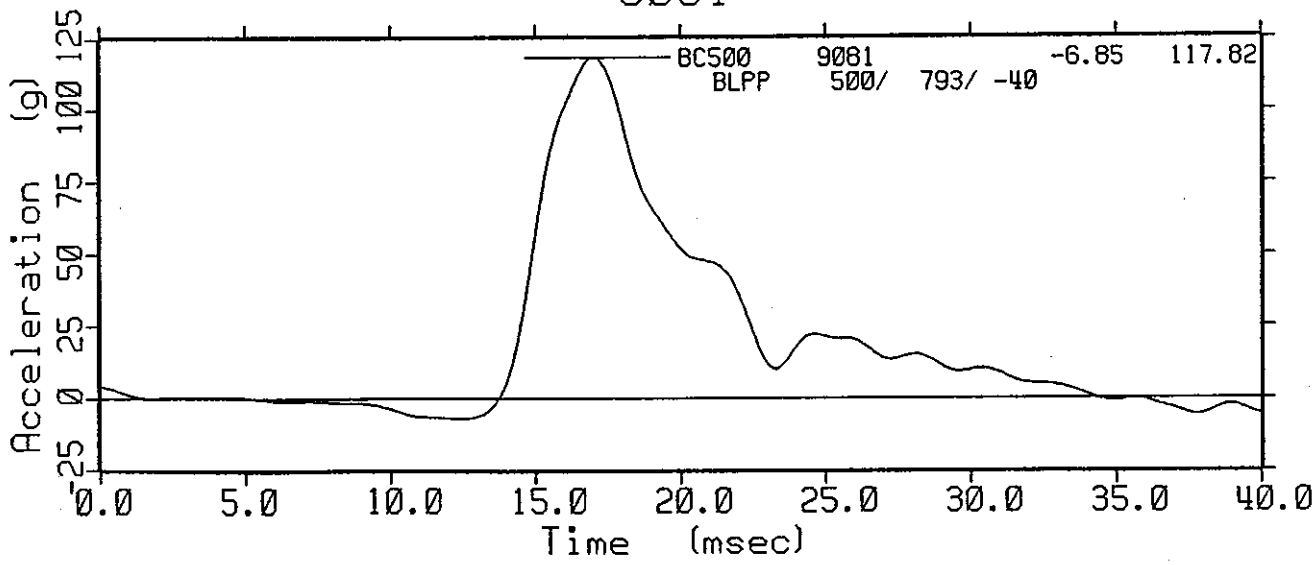

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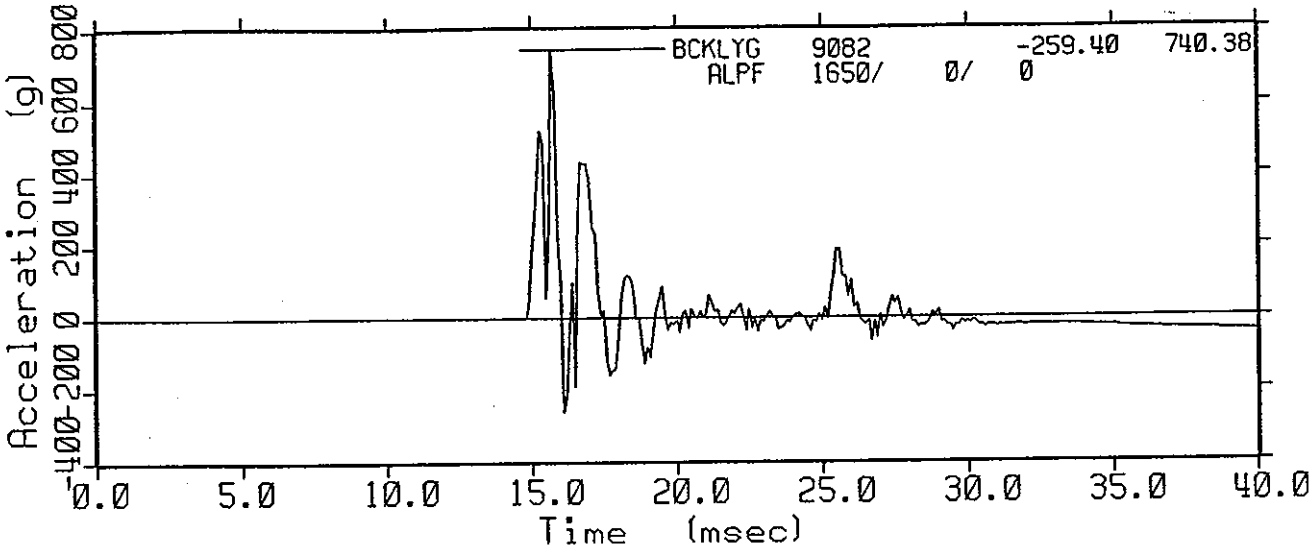

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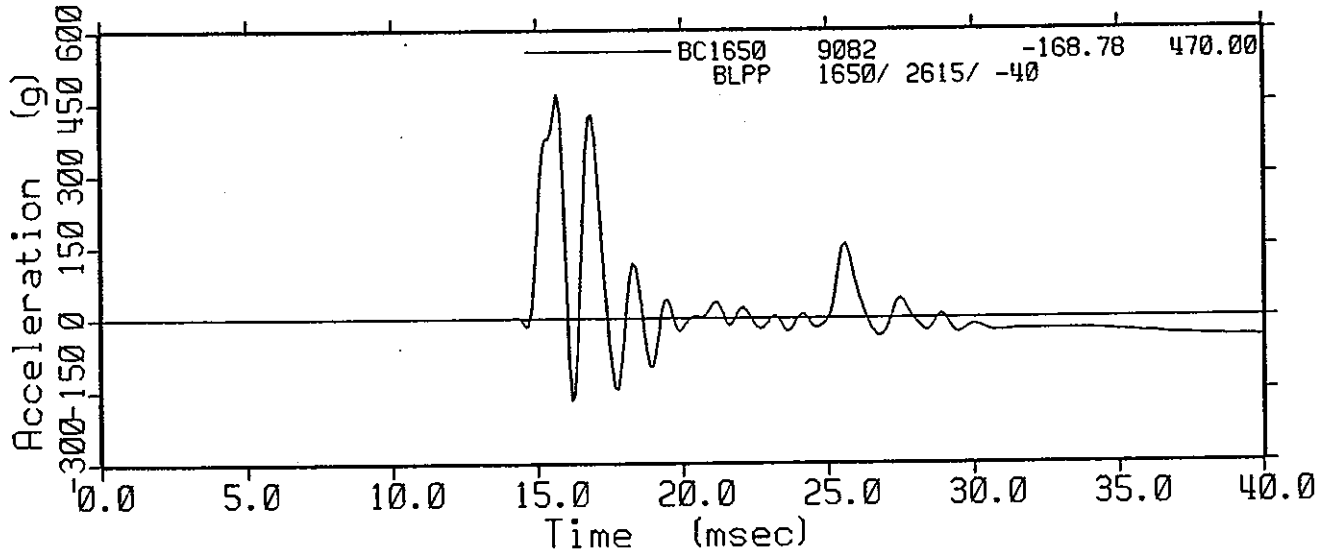

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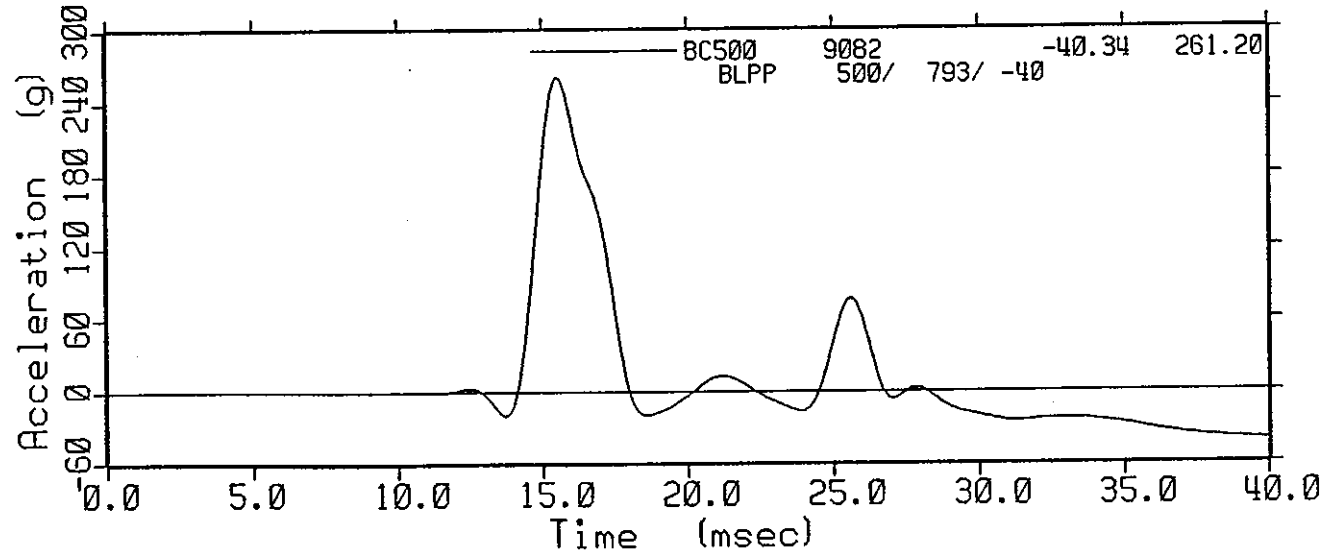

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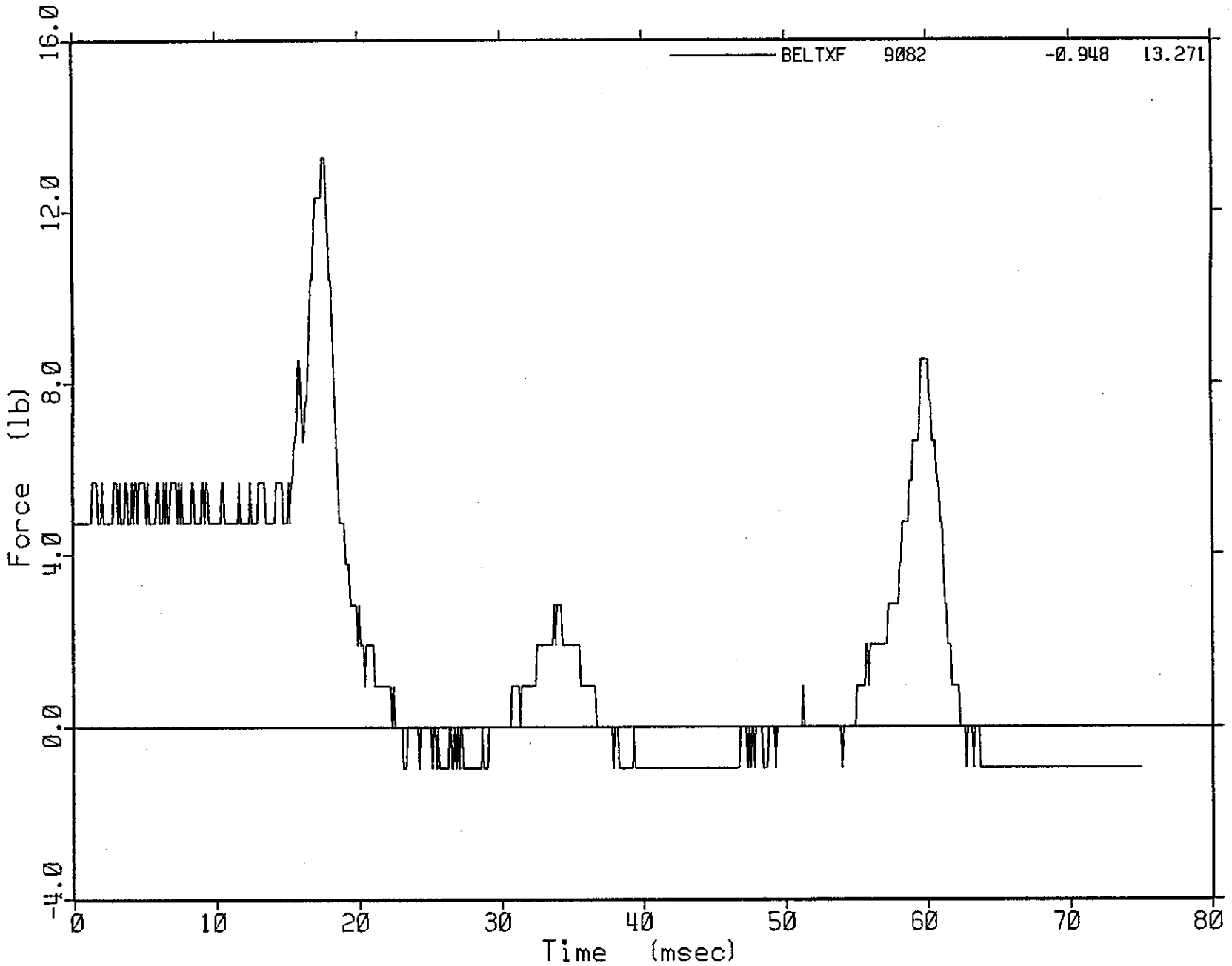

TEST 9082 - FORCE

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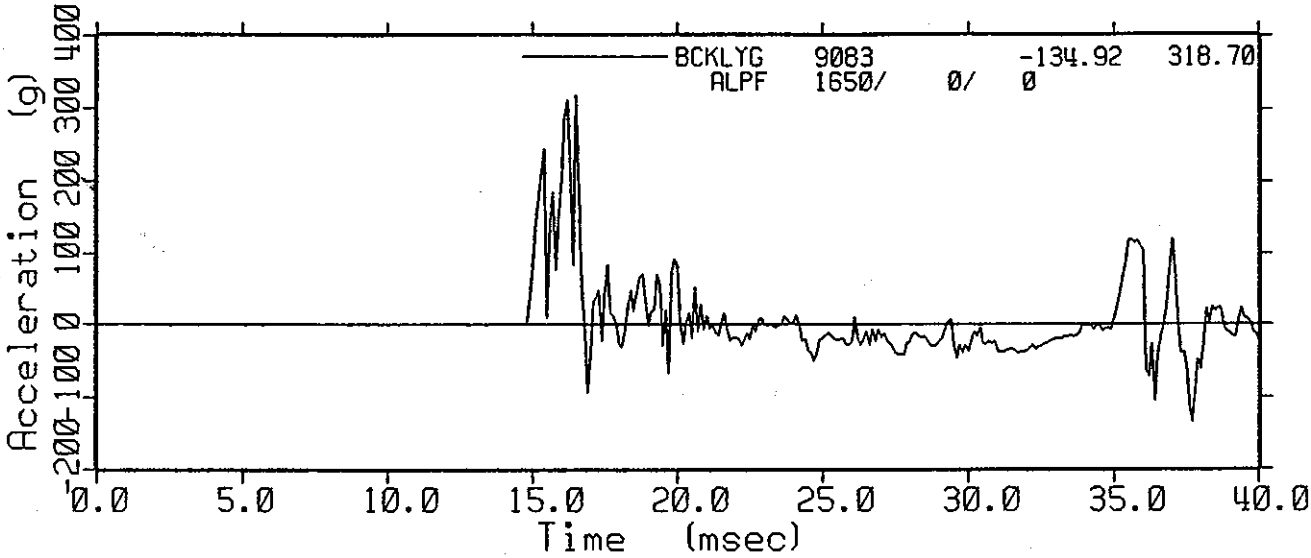

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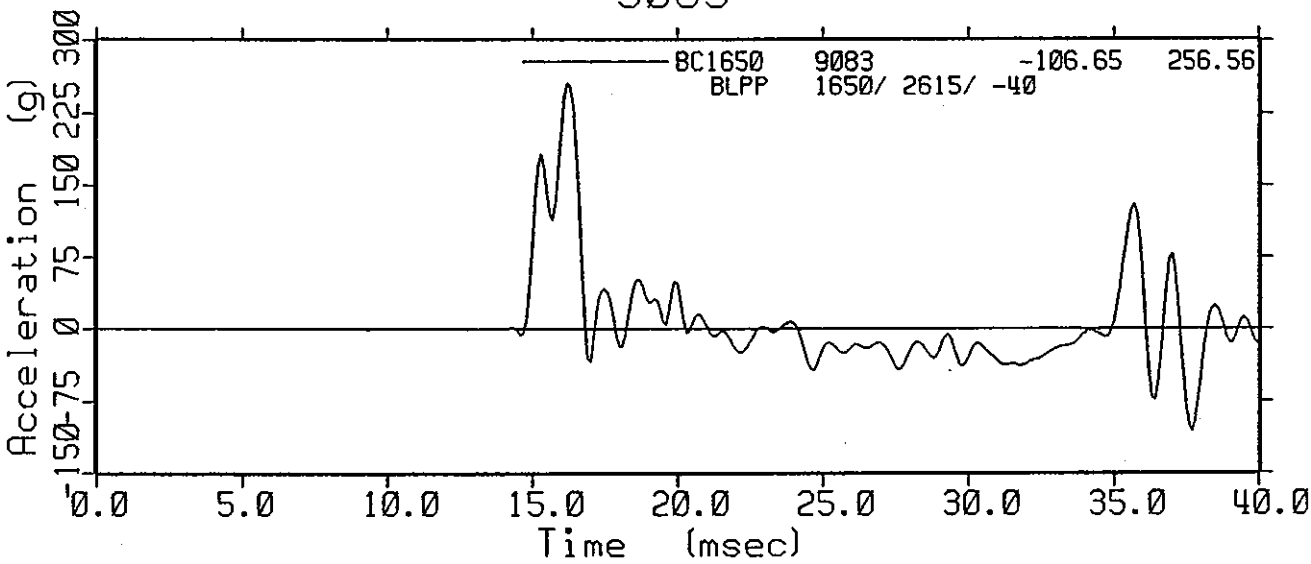

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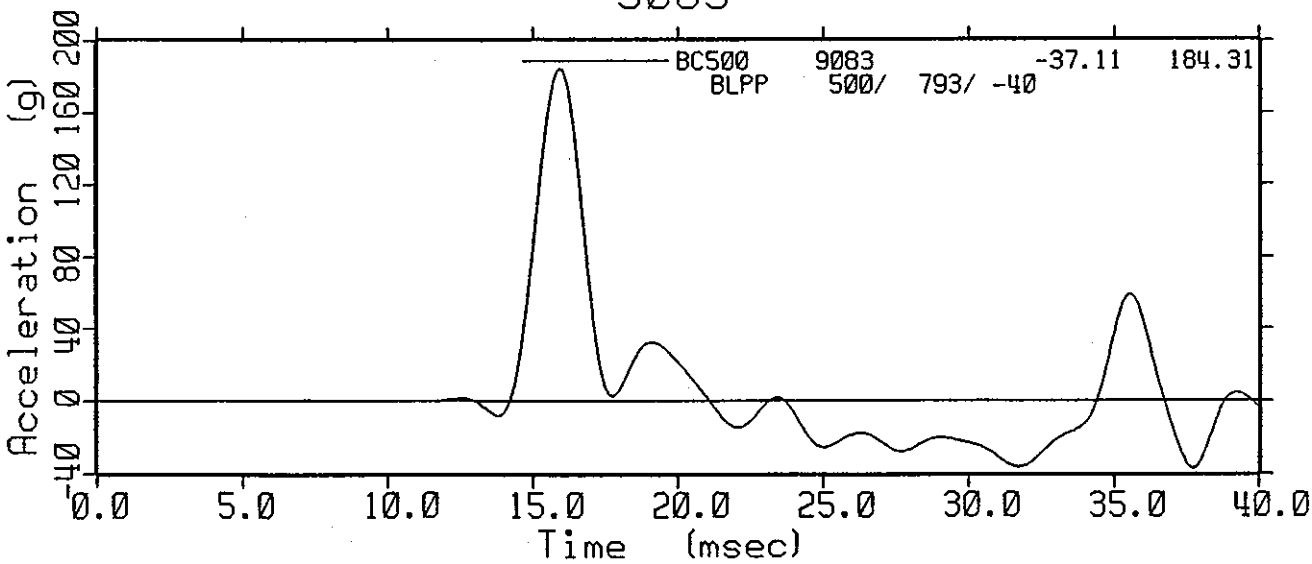

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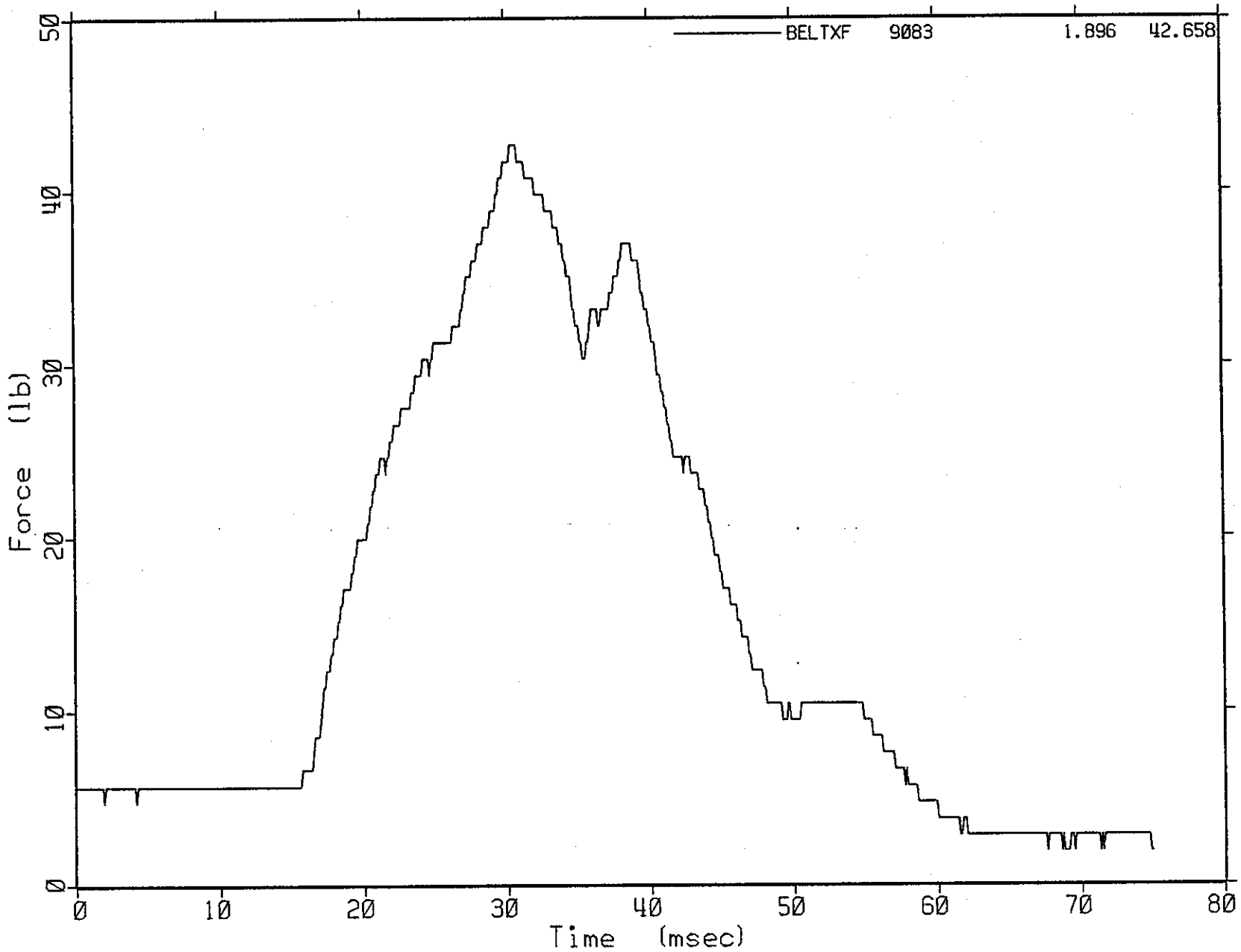

TEST 9083 - FORCE

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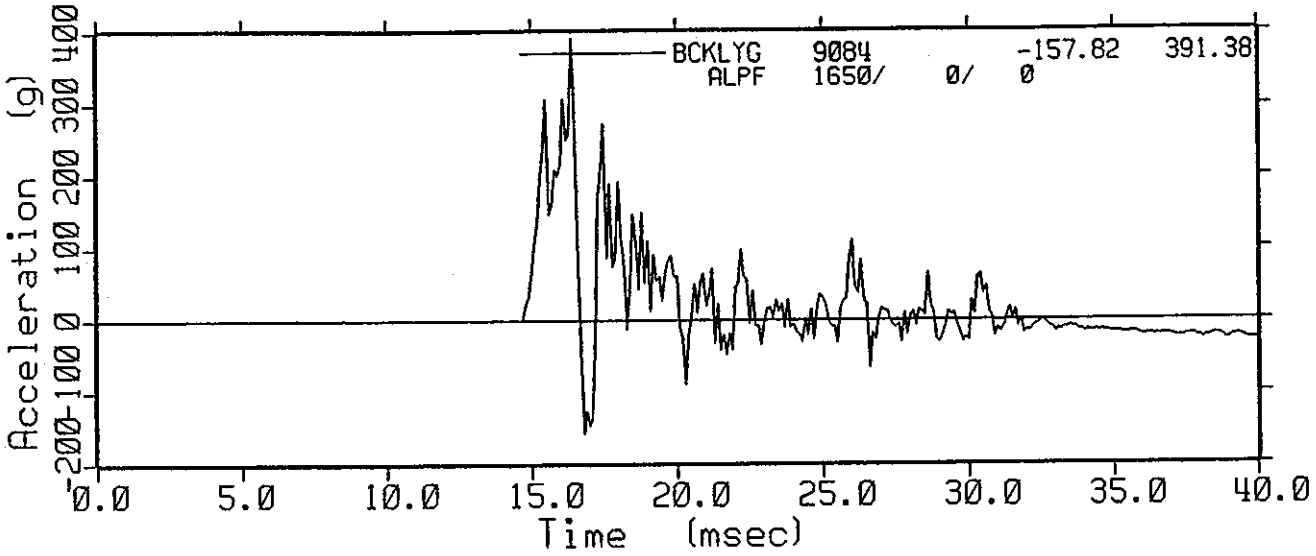

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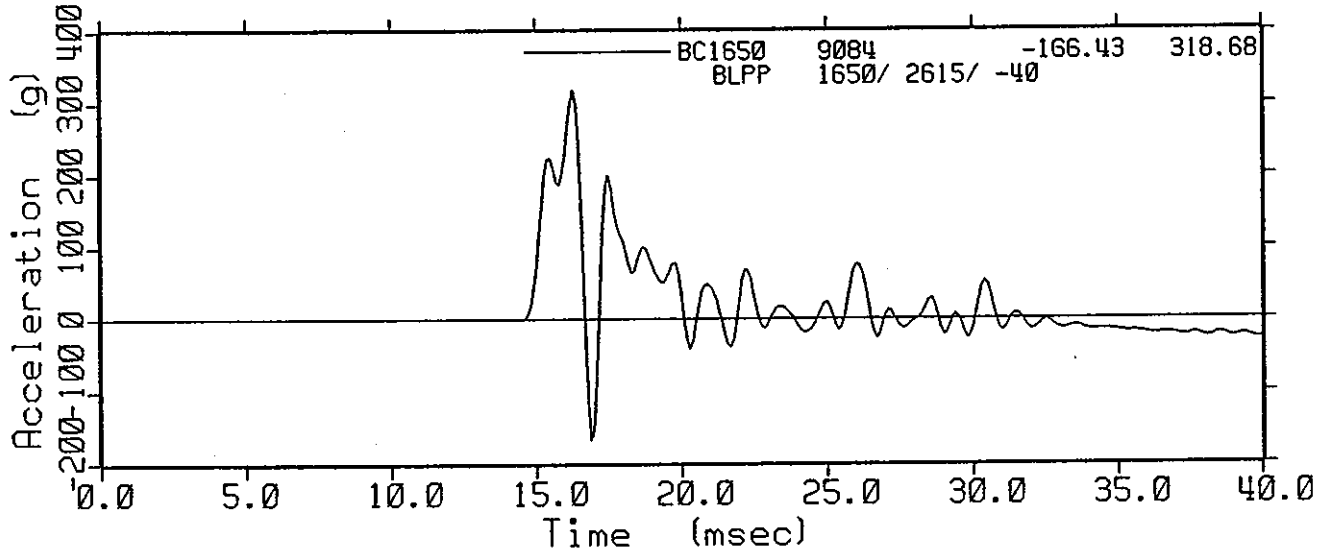

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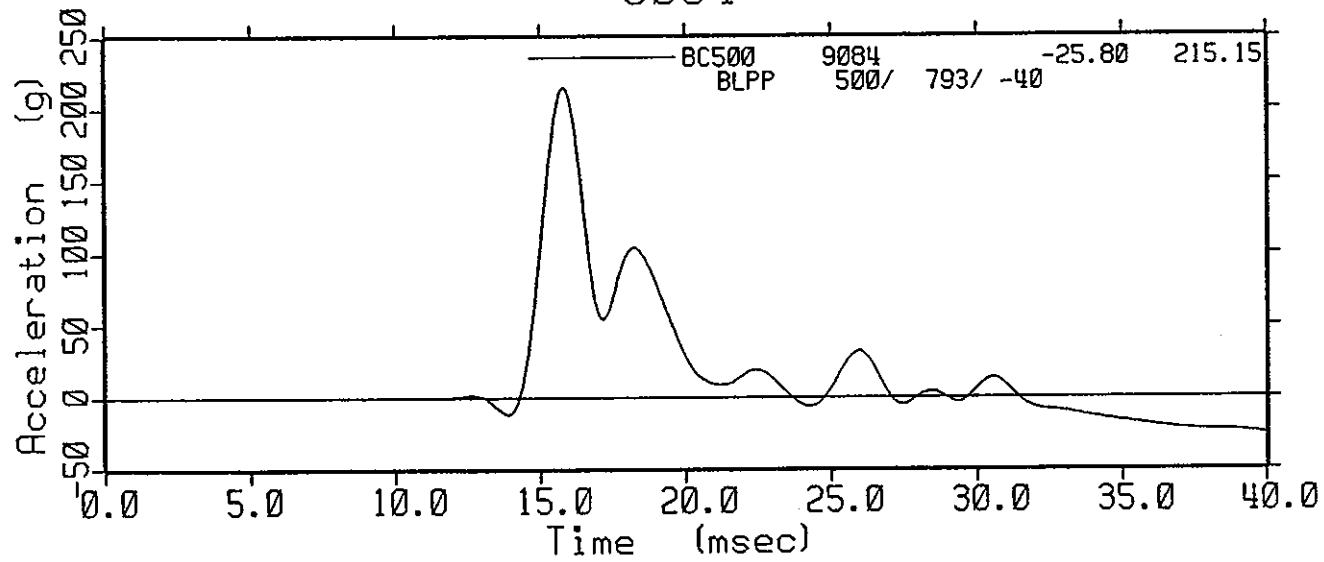

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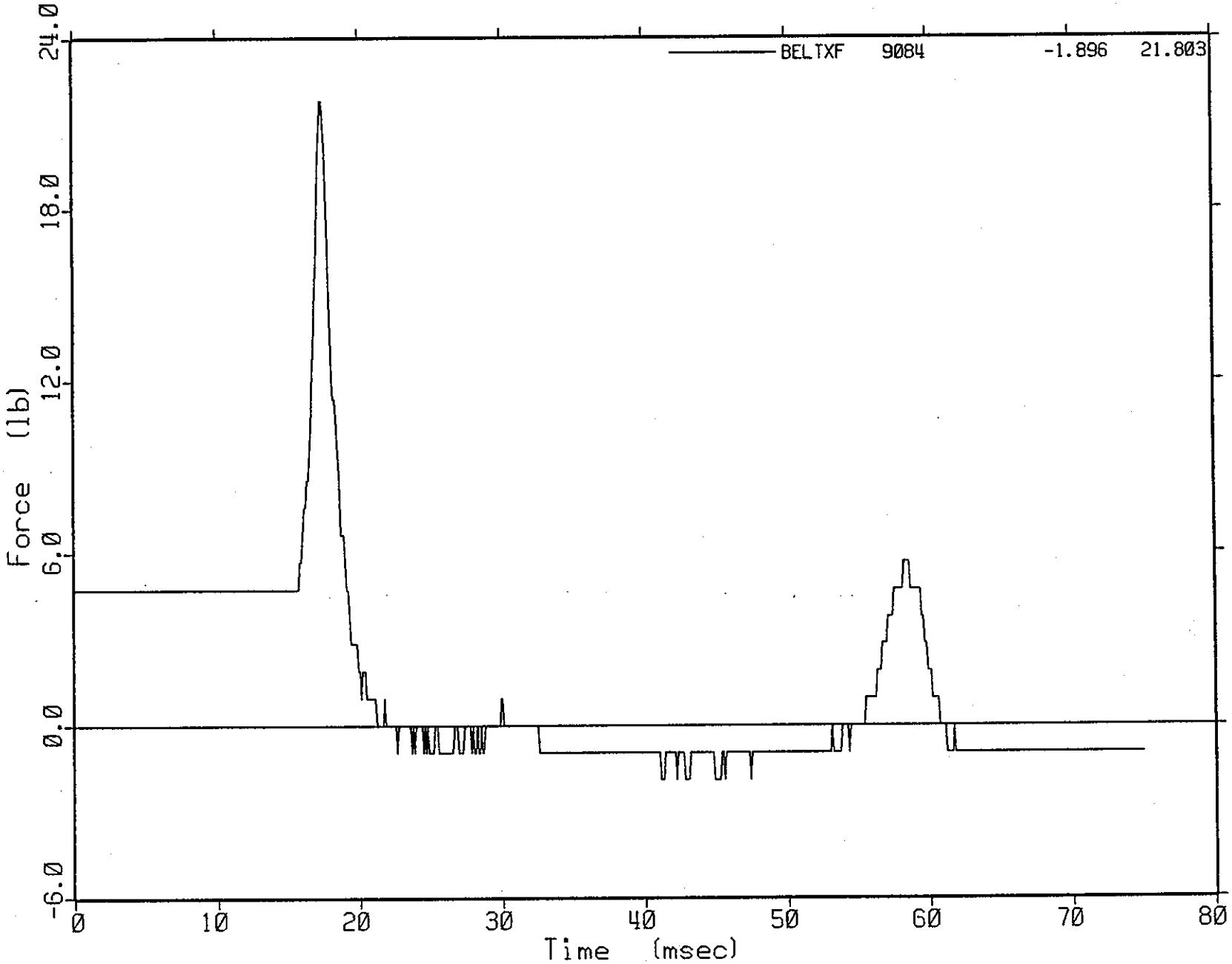

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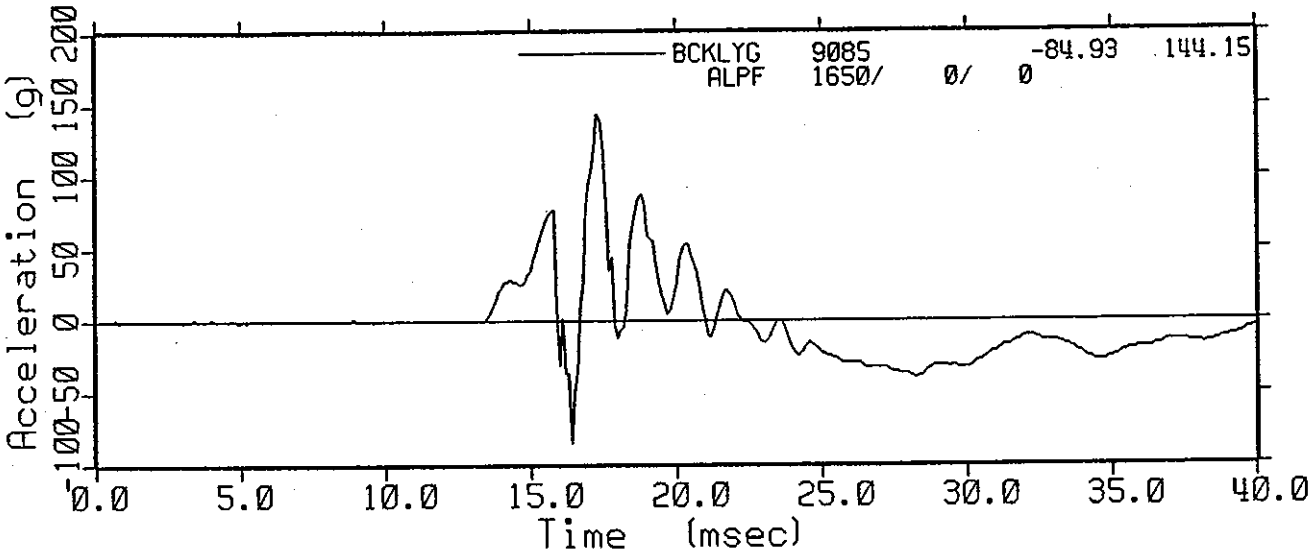

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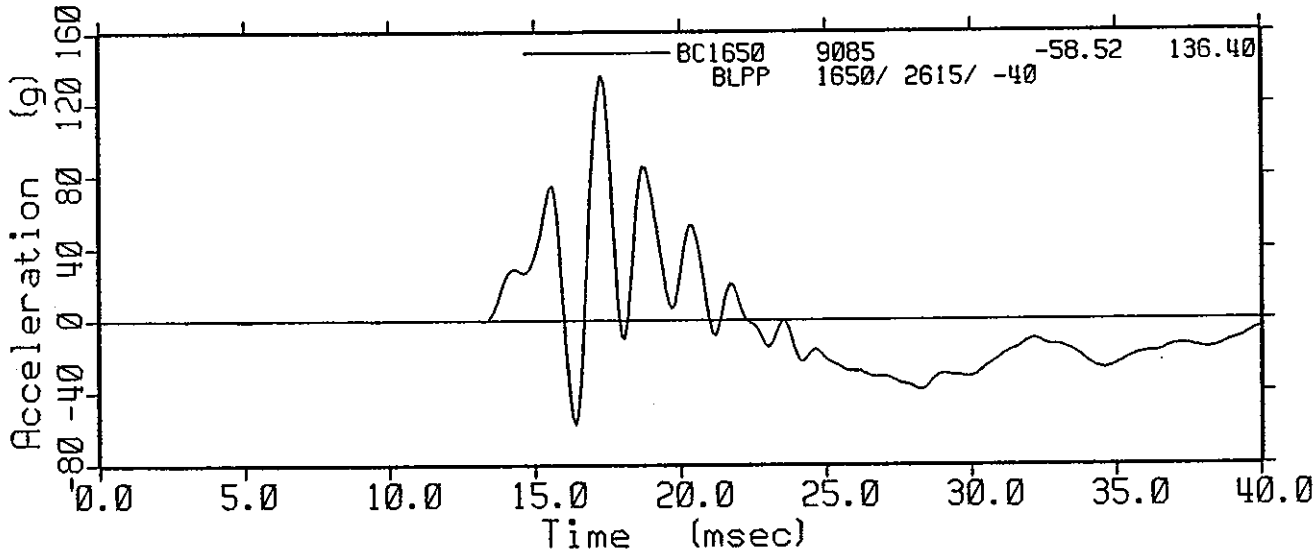

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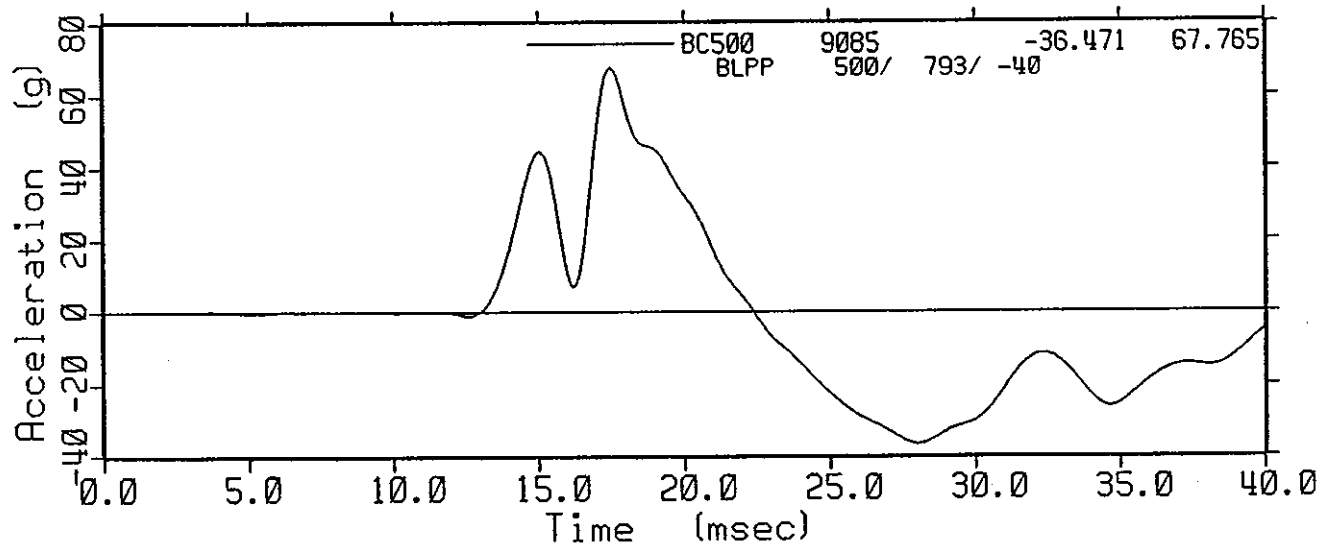

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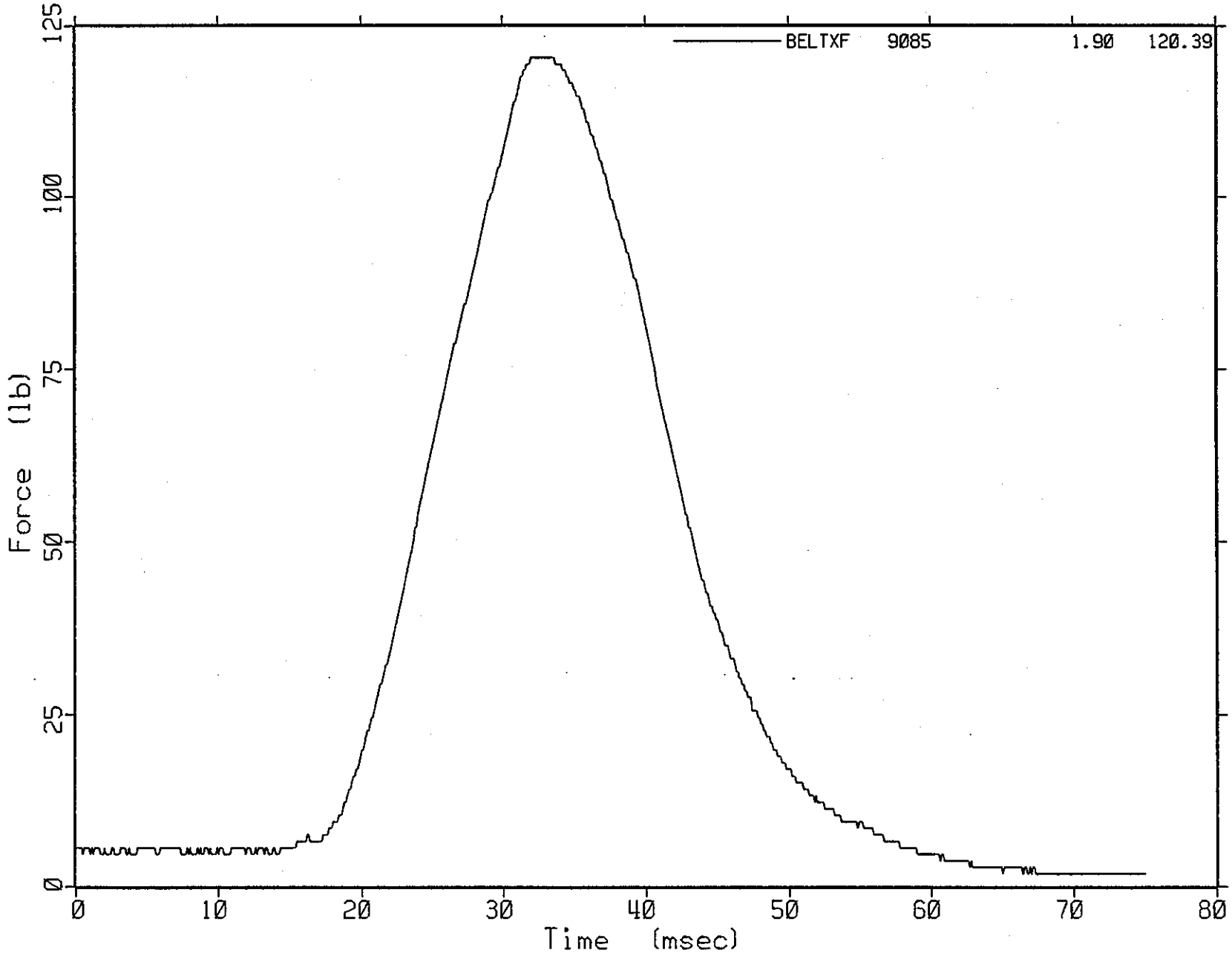
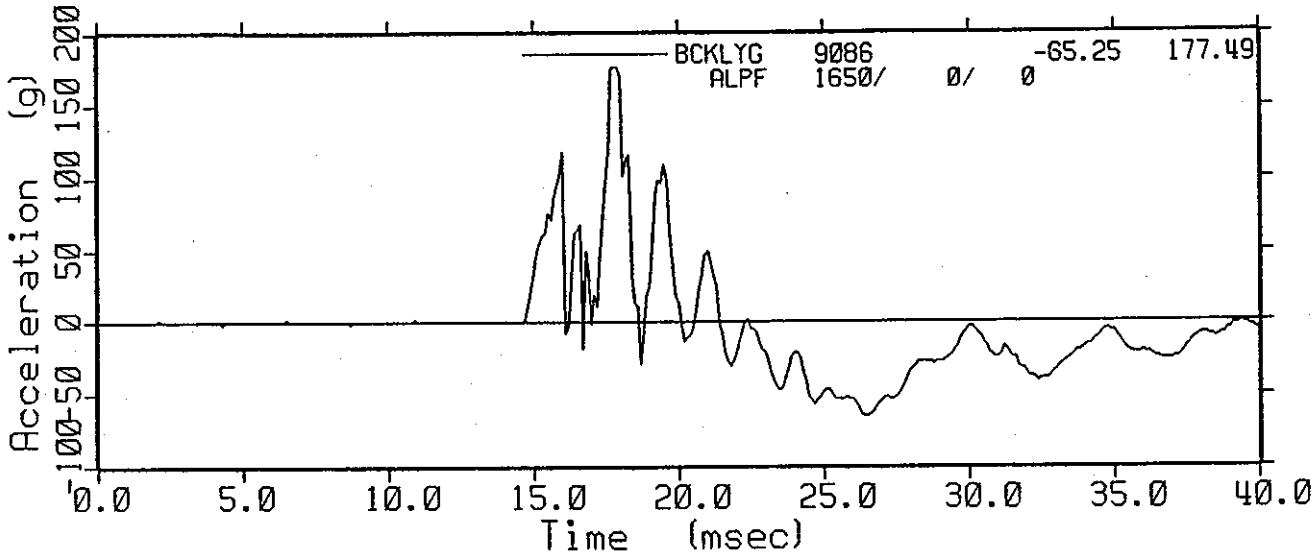
8-OCT-92 17:00



TEST 9085 - FORCE

8-OCT-92 20:25



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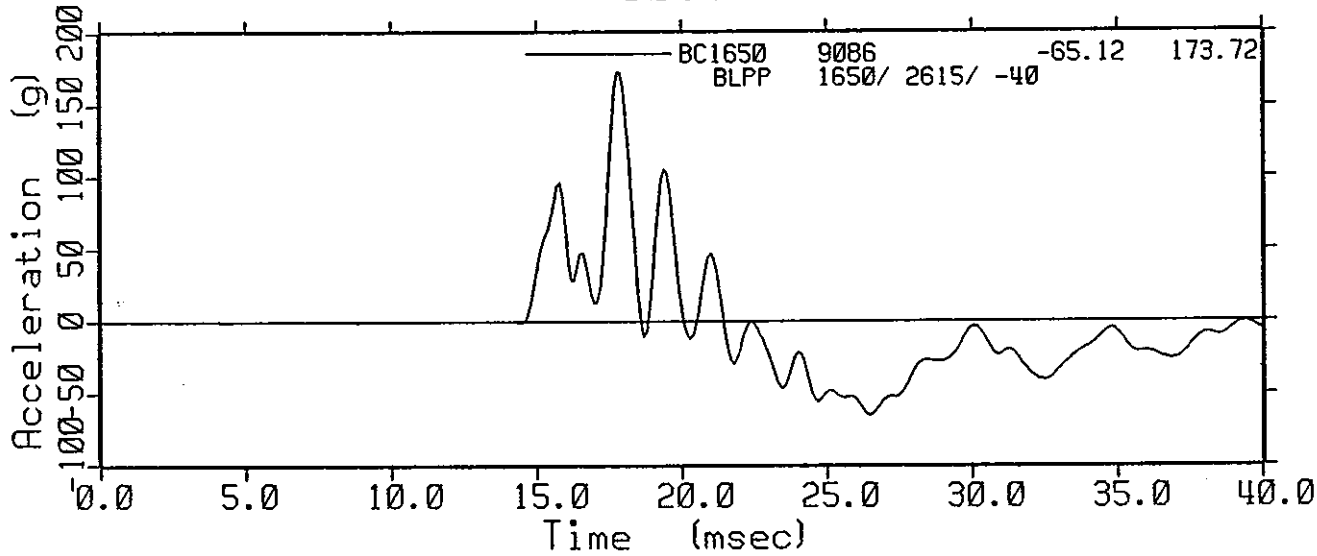

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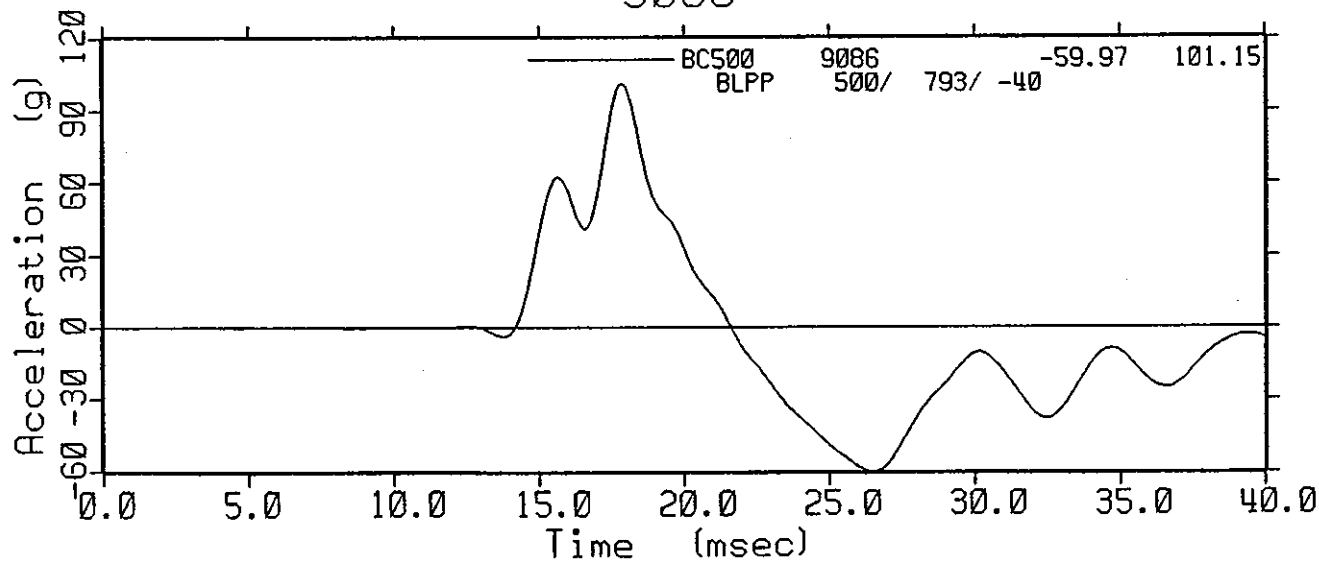

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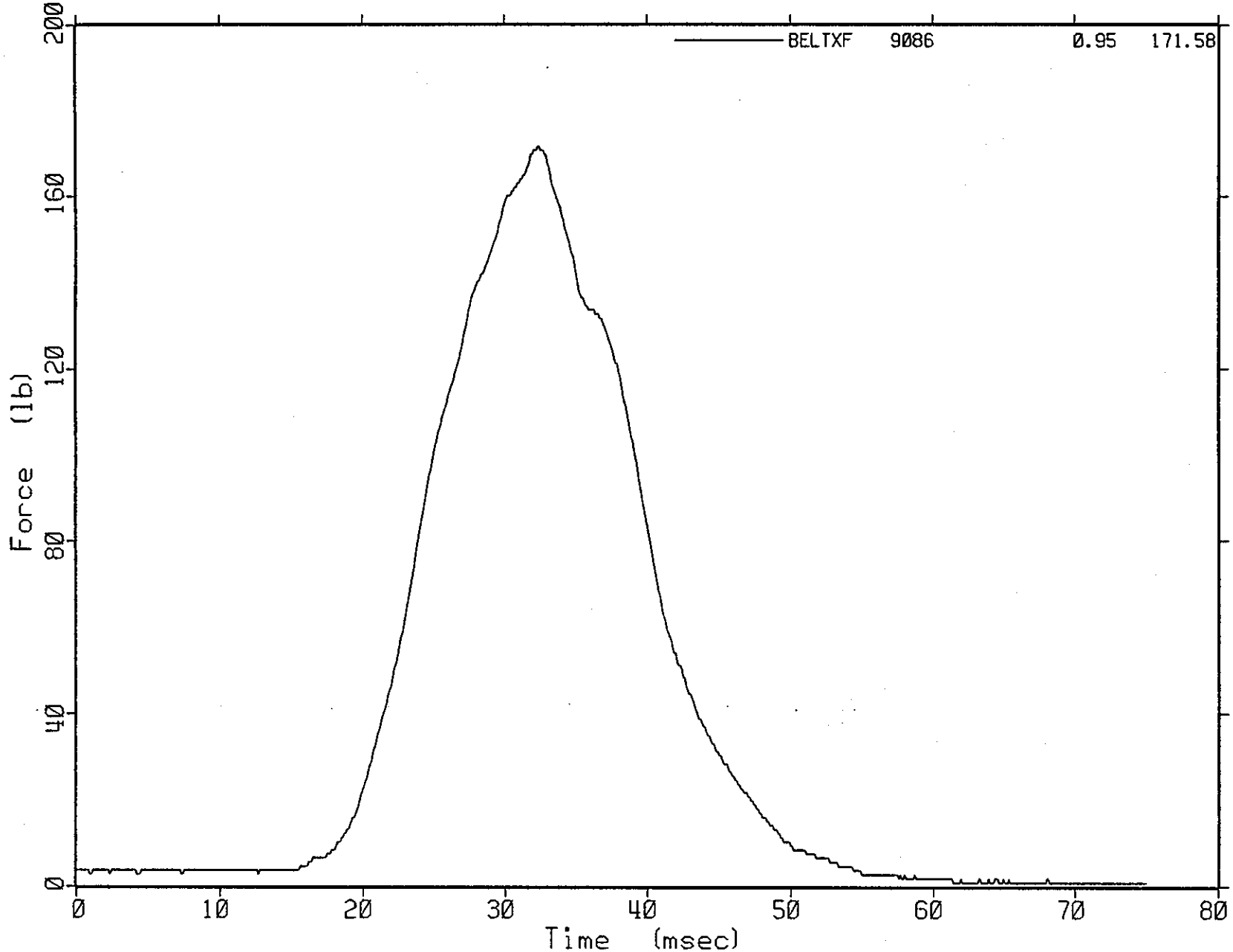

TEST 9086 - FORCE

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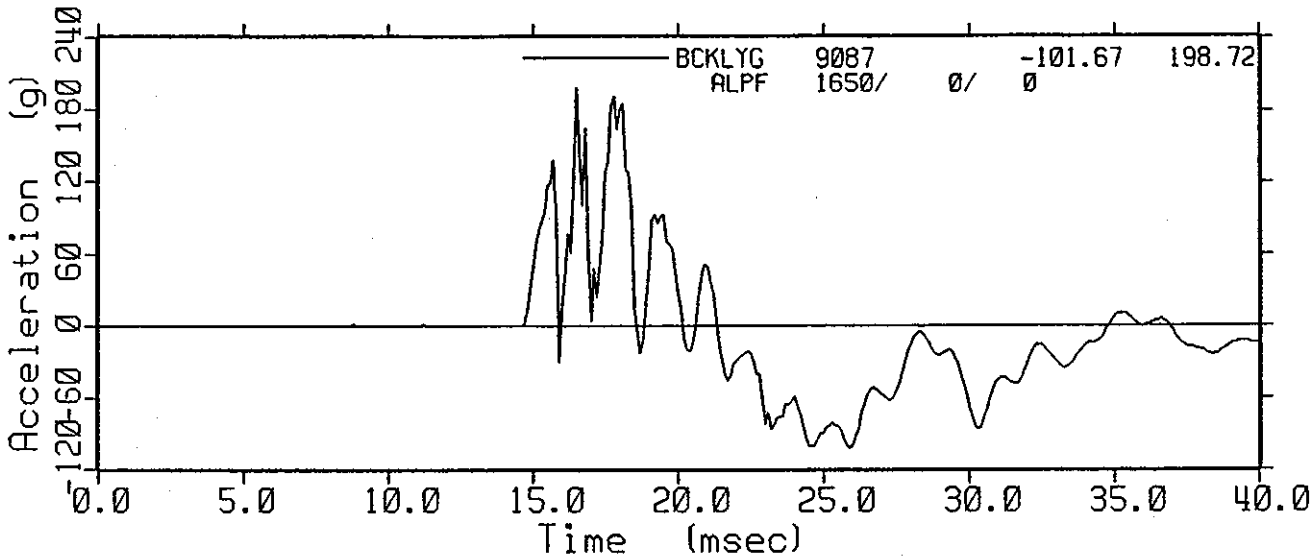

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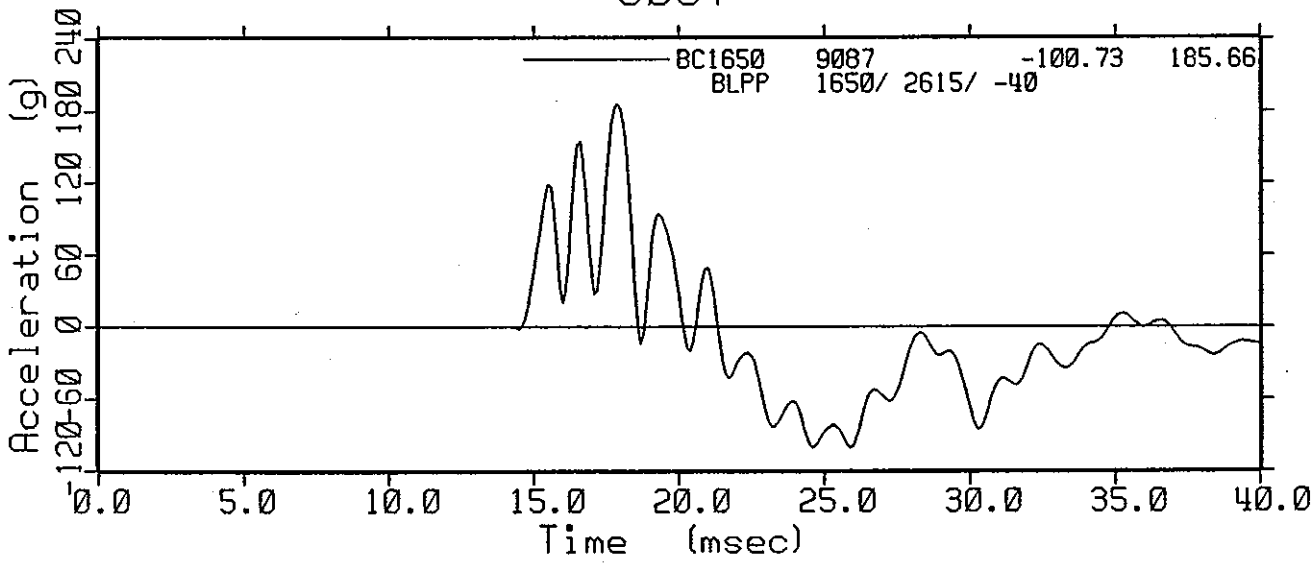

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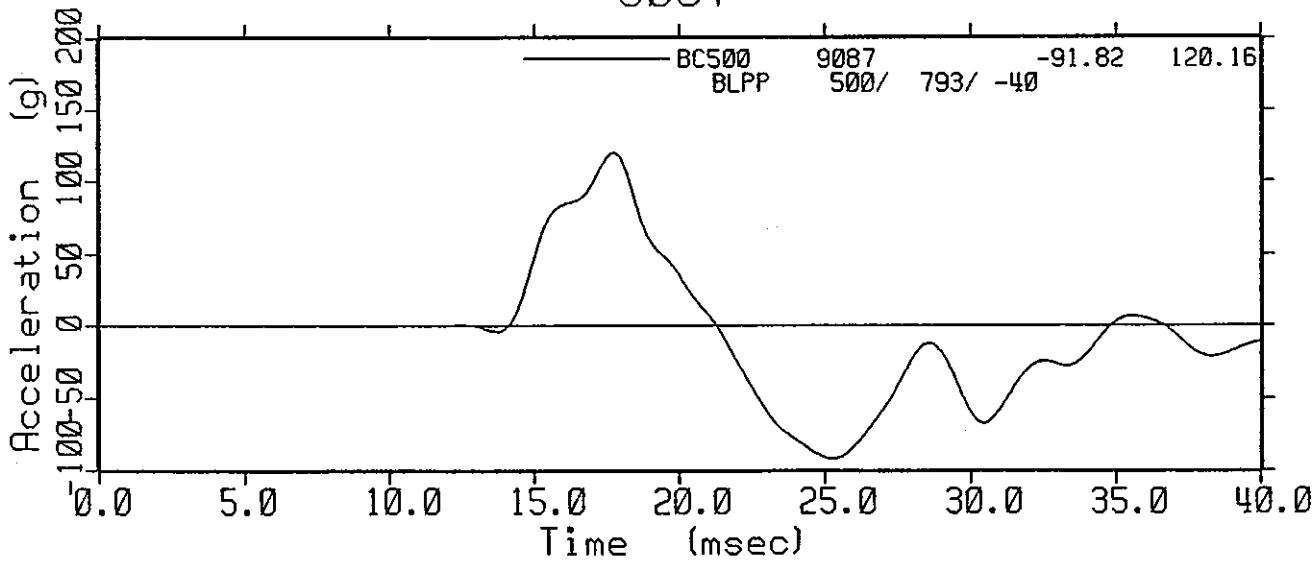

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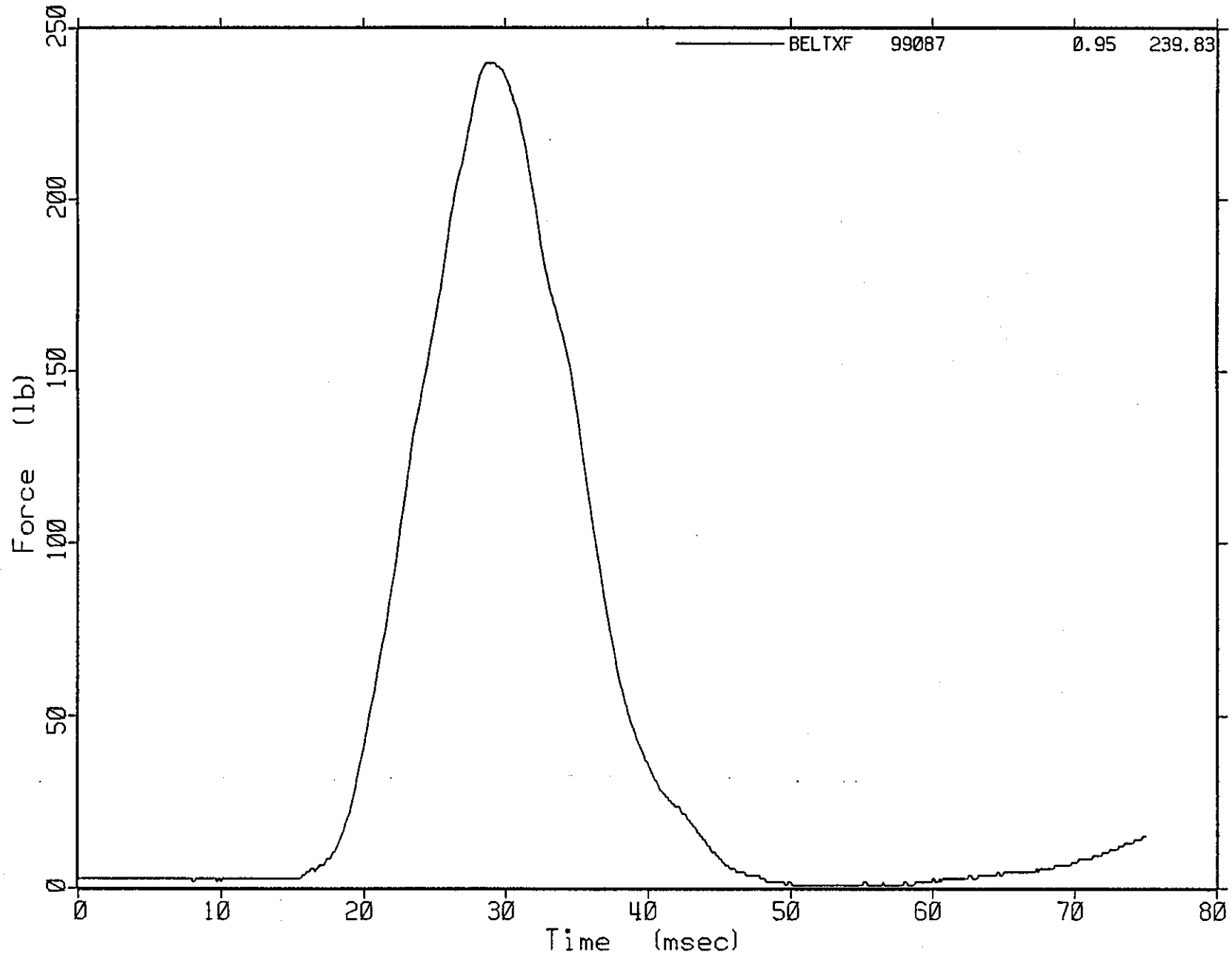

TEST 9087 - FORCE

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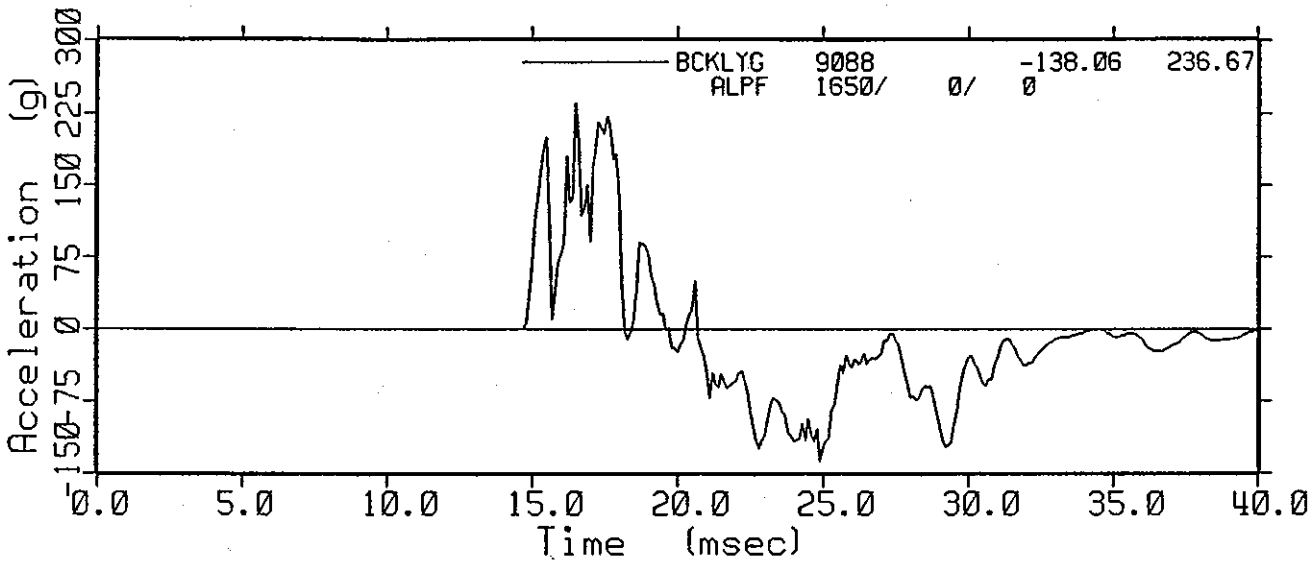

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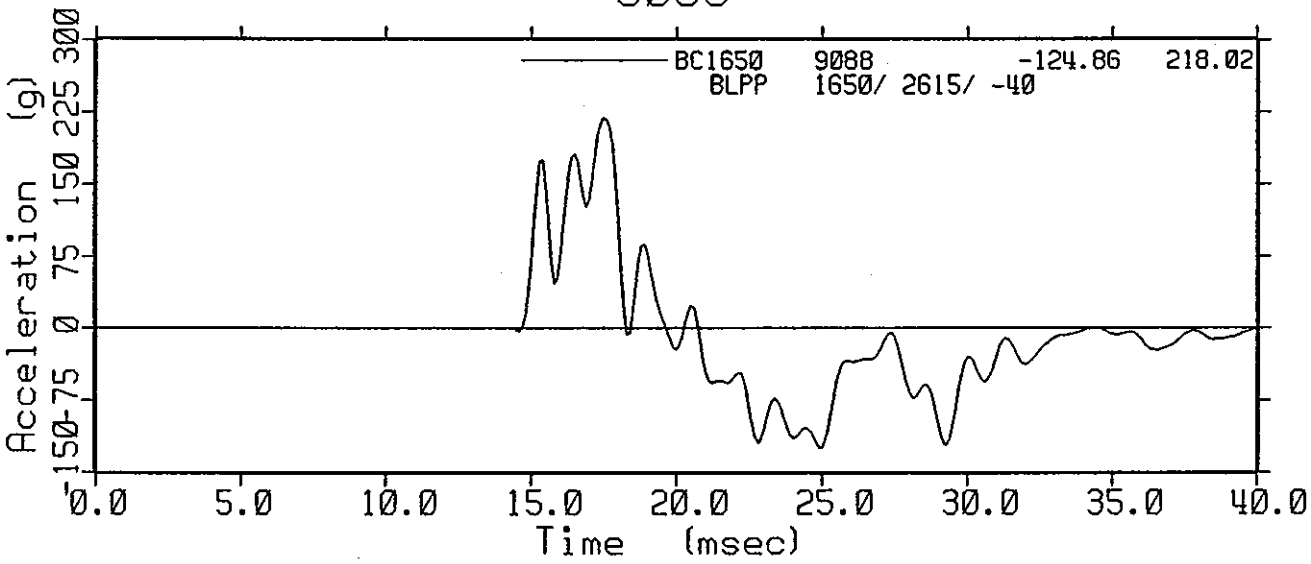

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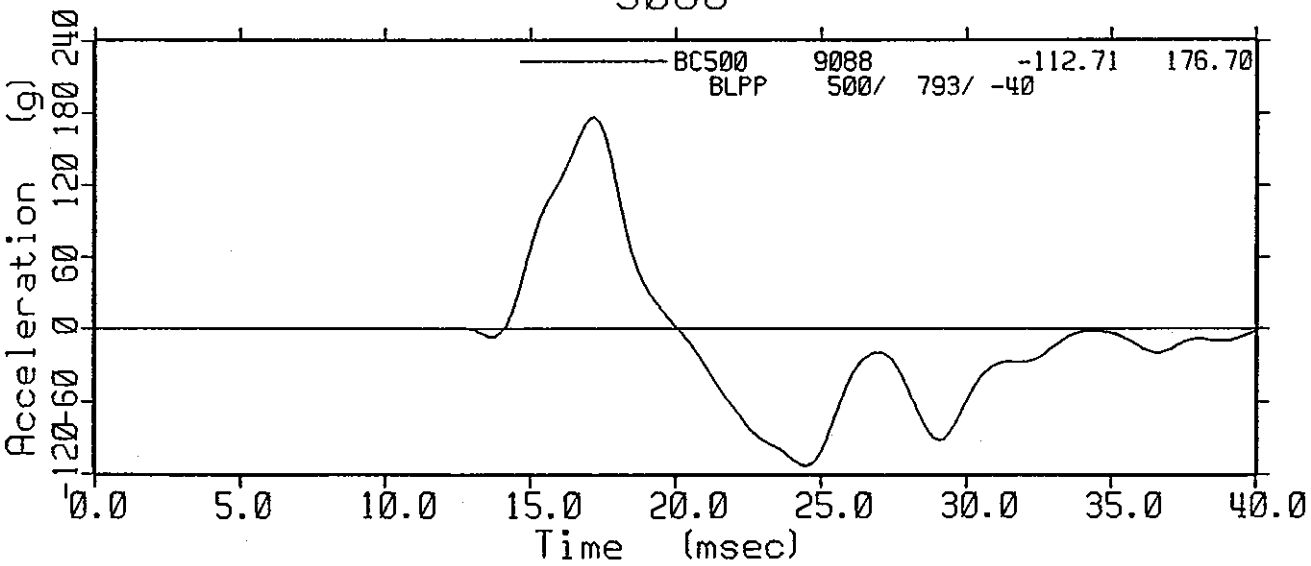

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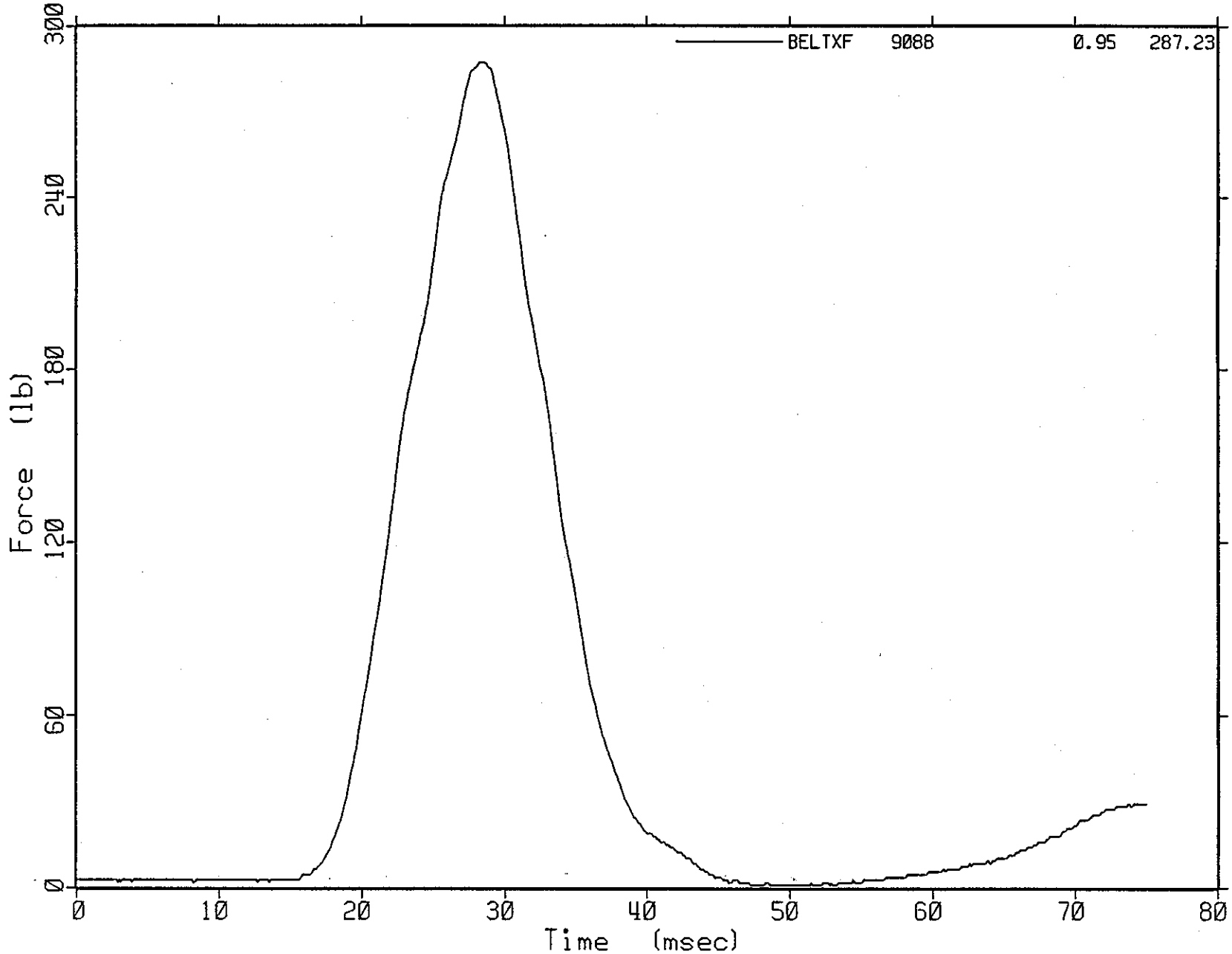

TEST 9088 - FORCE

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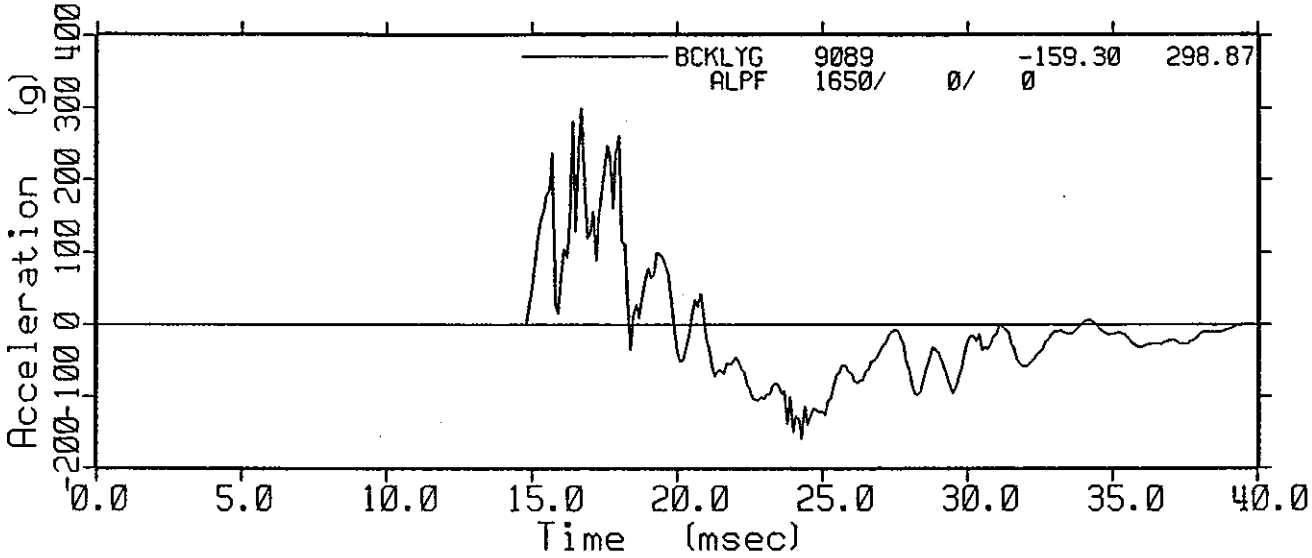

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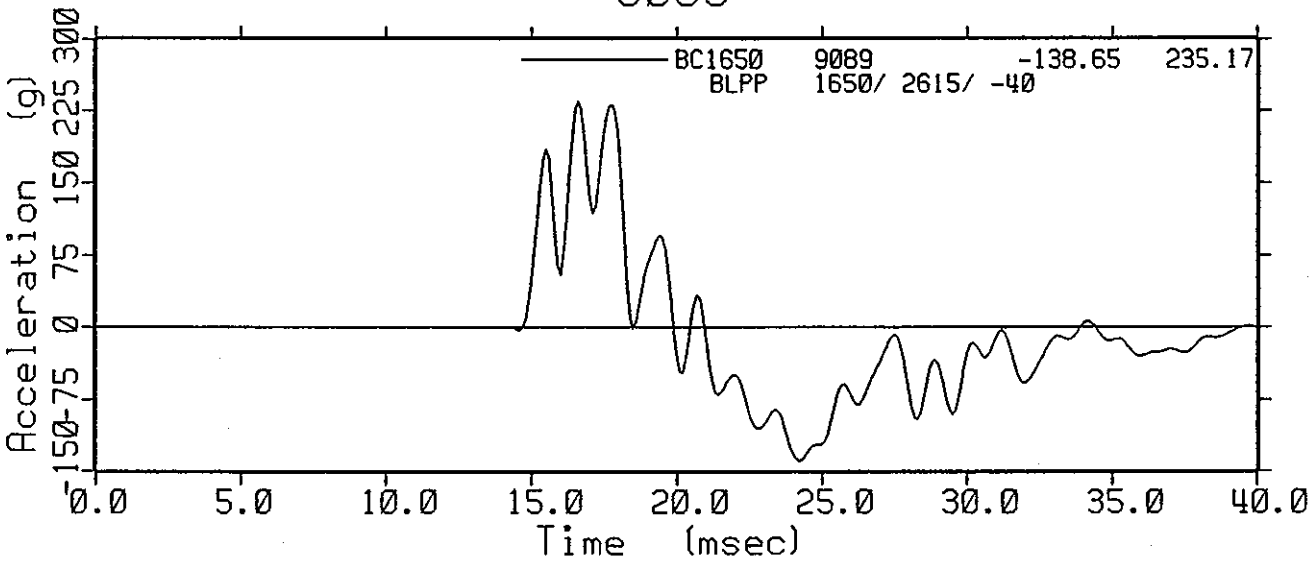

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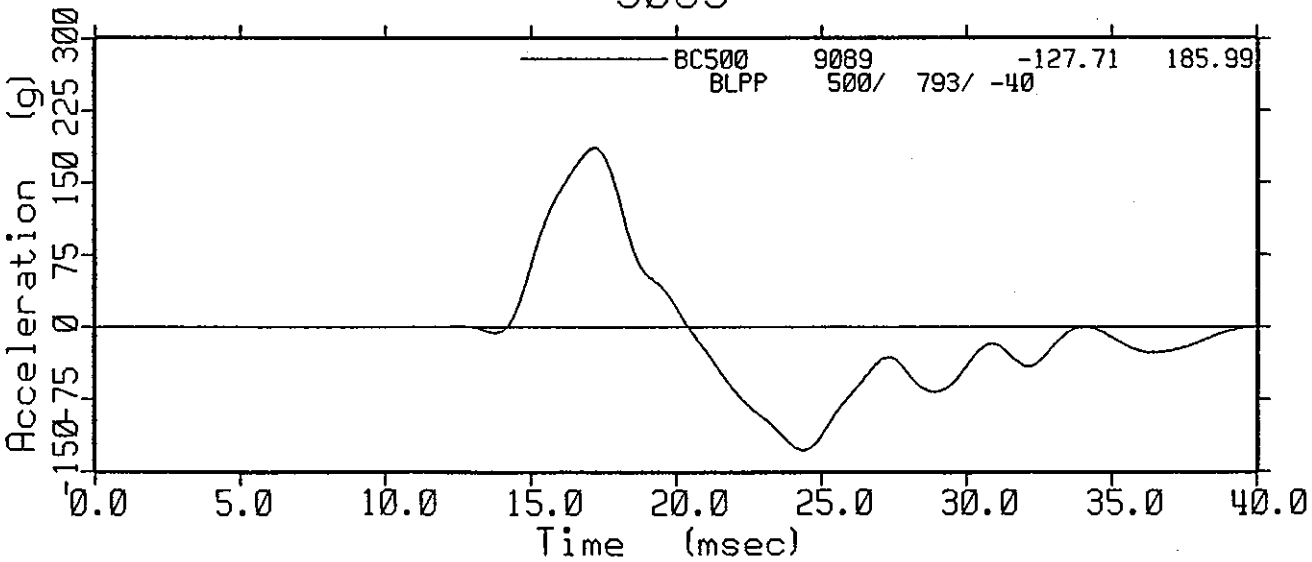

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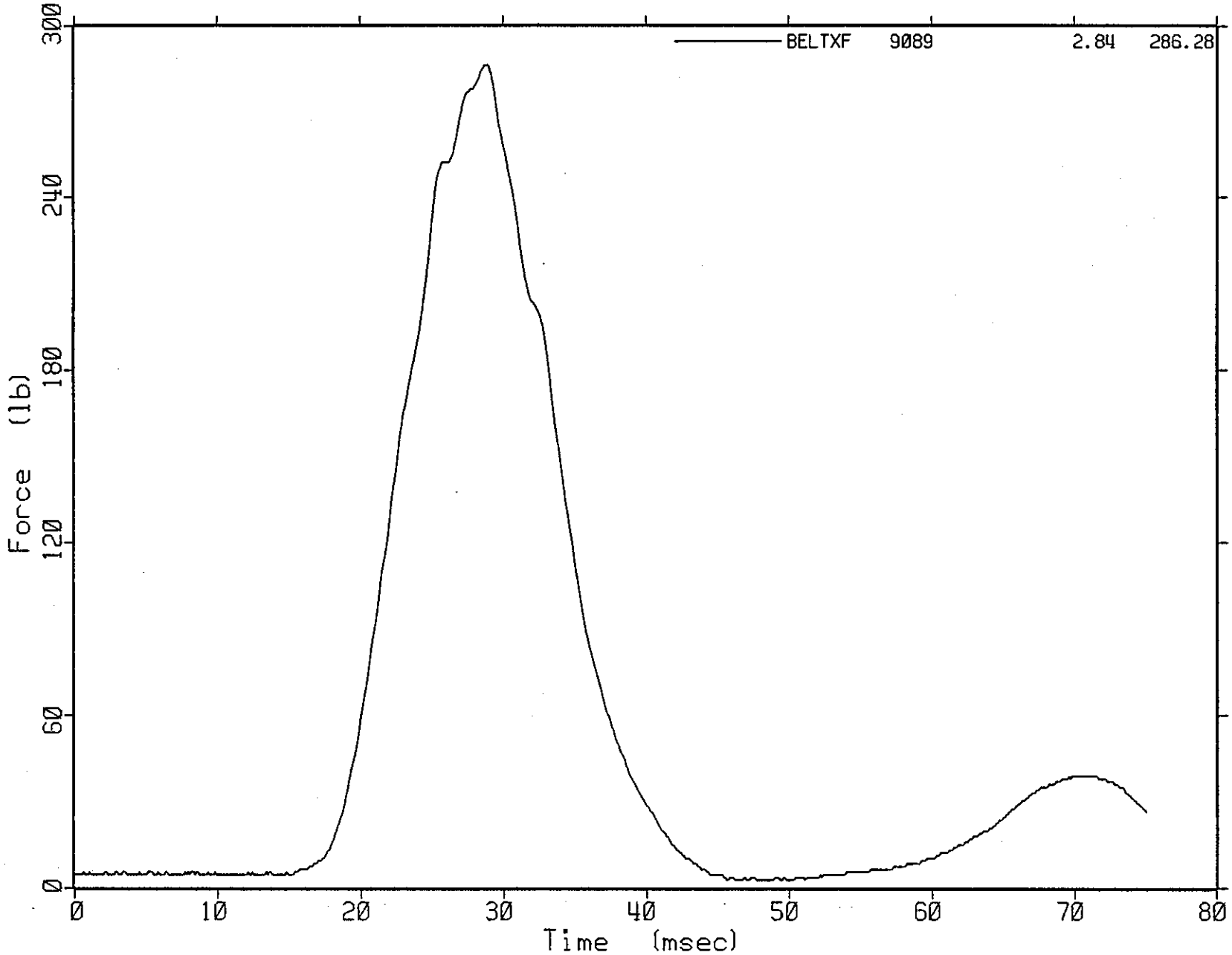

TEST 9089 - FORCE

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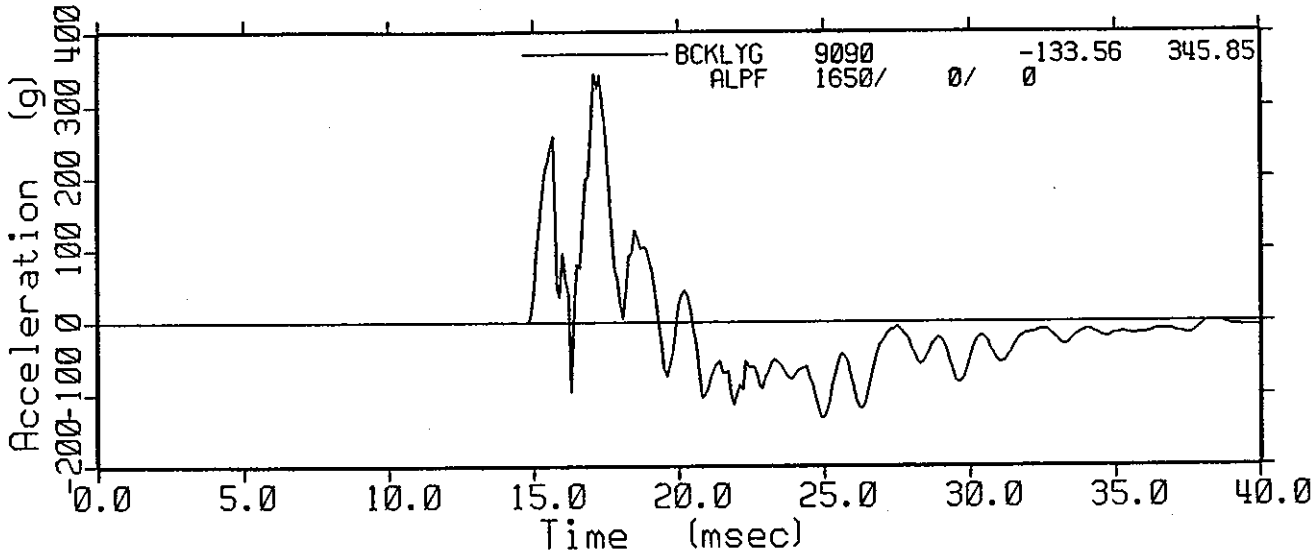

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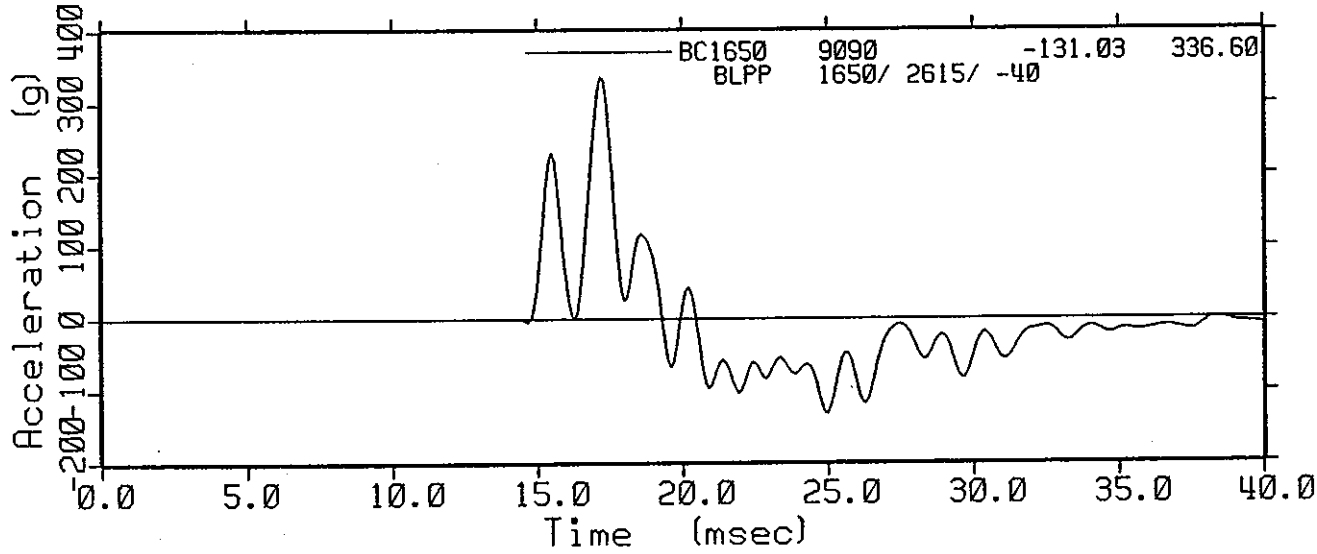

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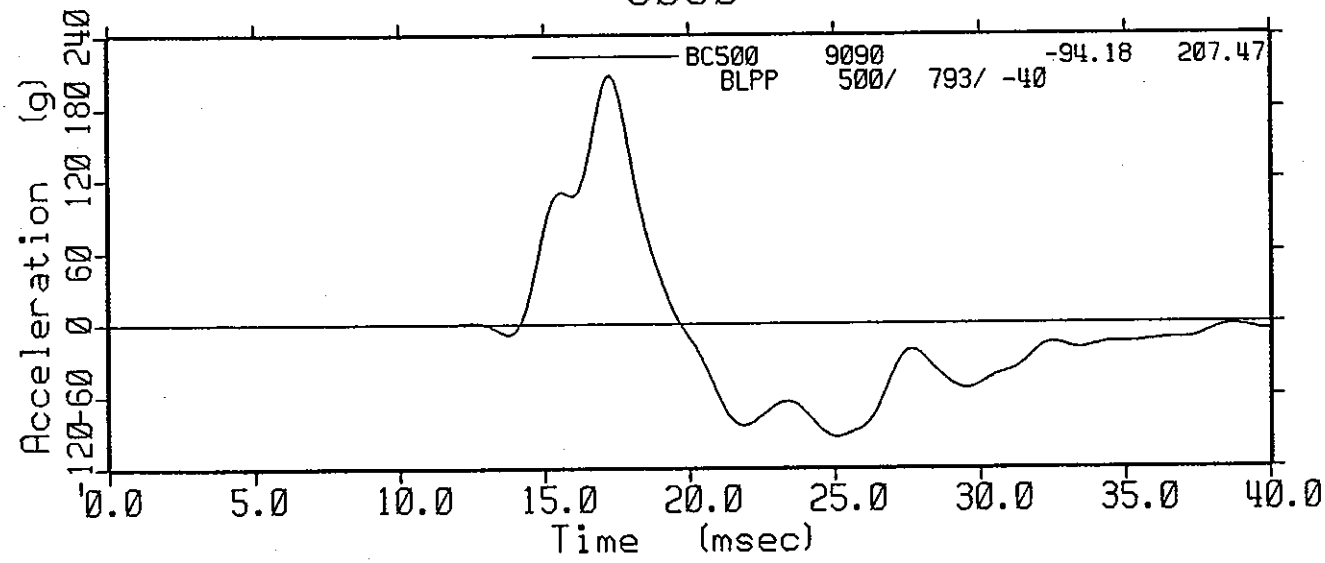

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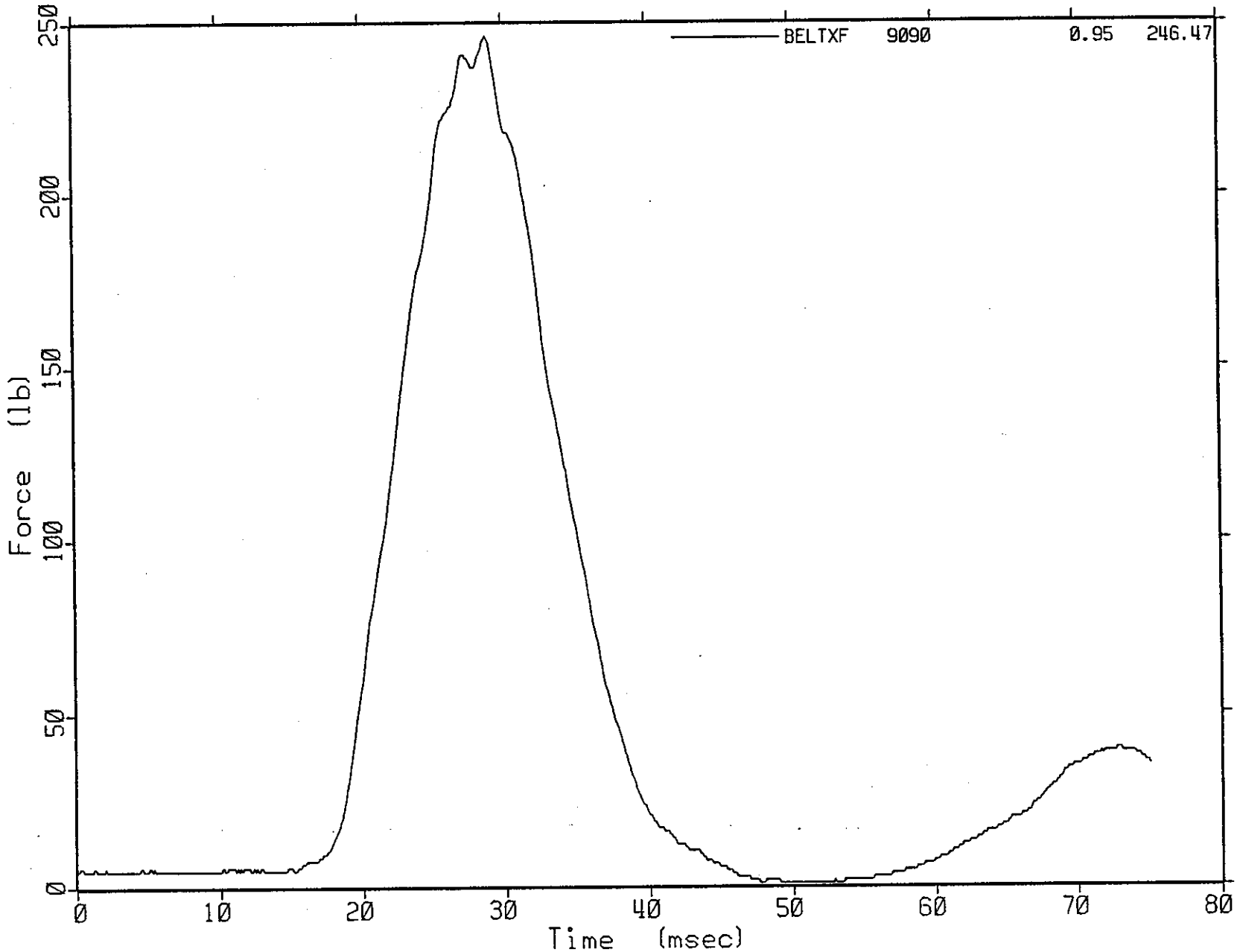

TEST 9090 - FORCE

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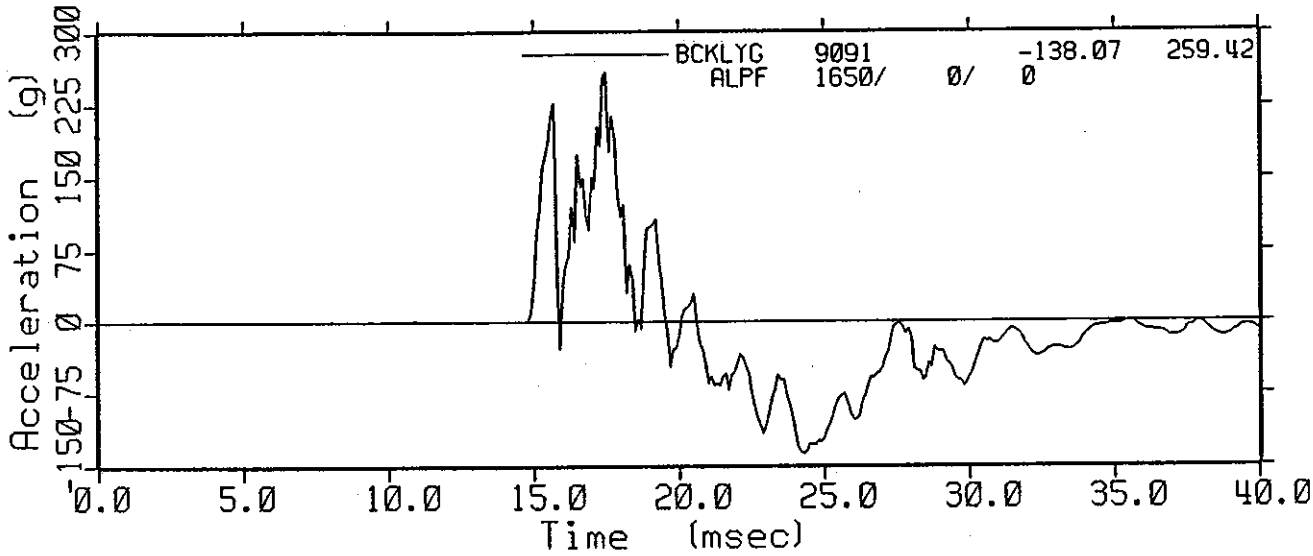

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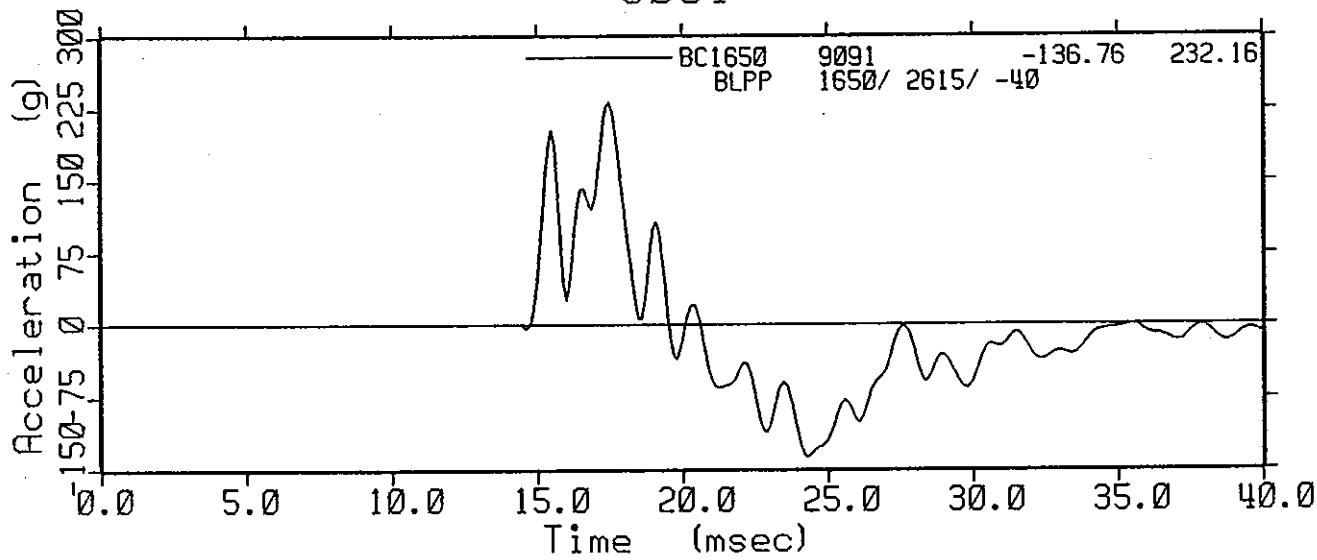

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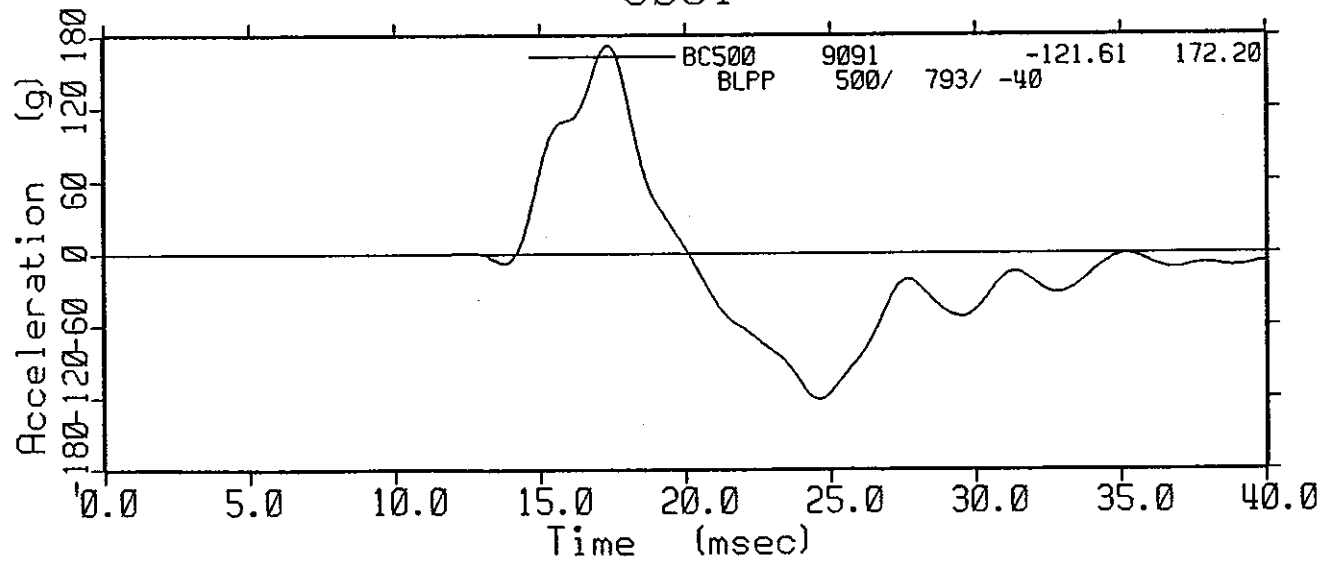

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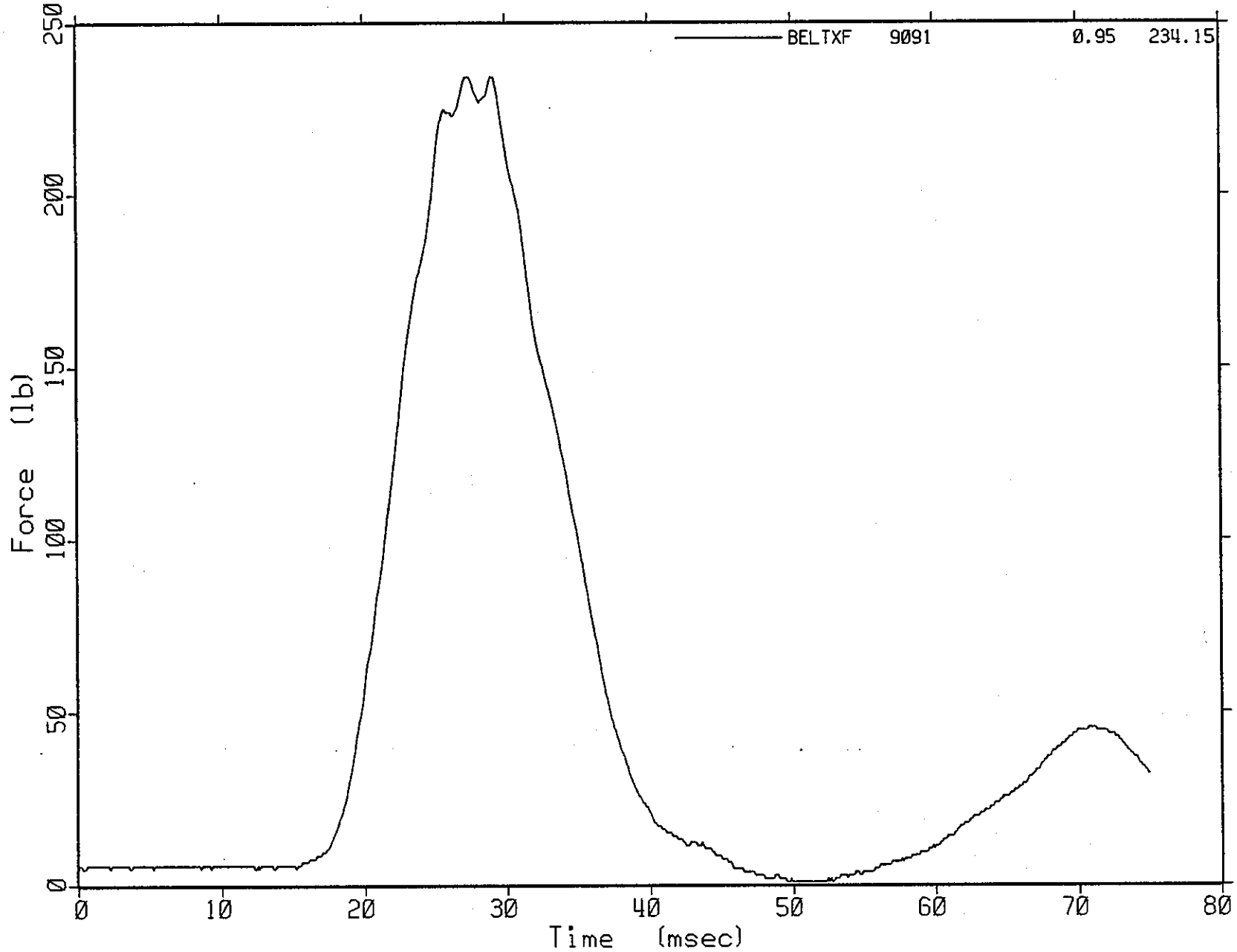

TEST 9091 - FORCE

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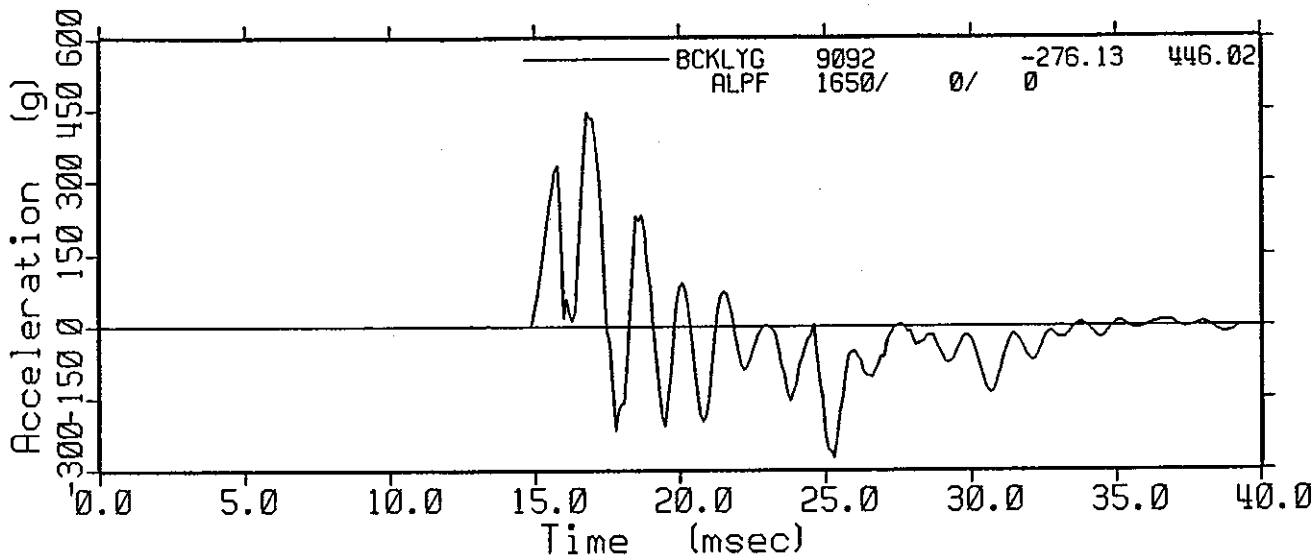

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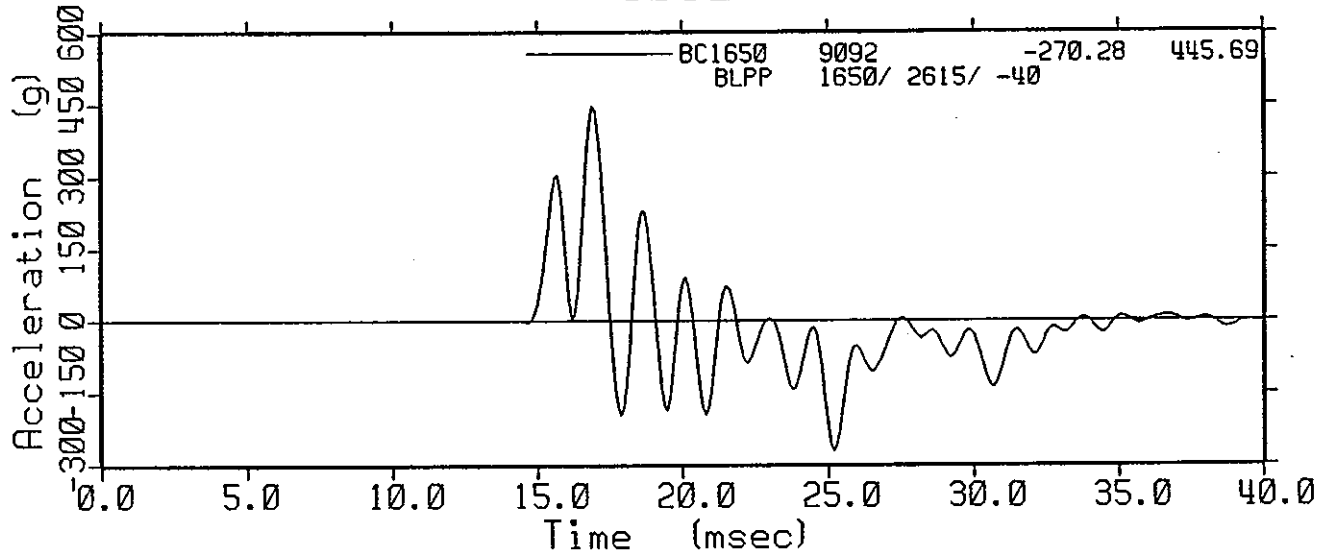

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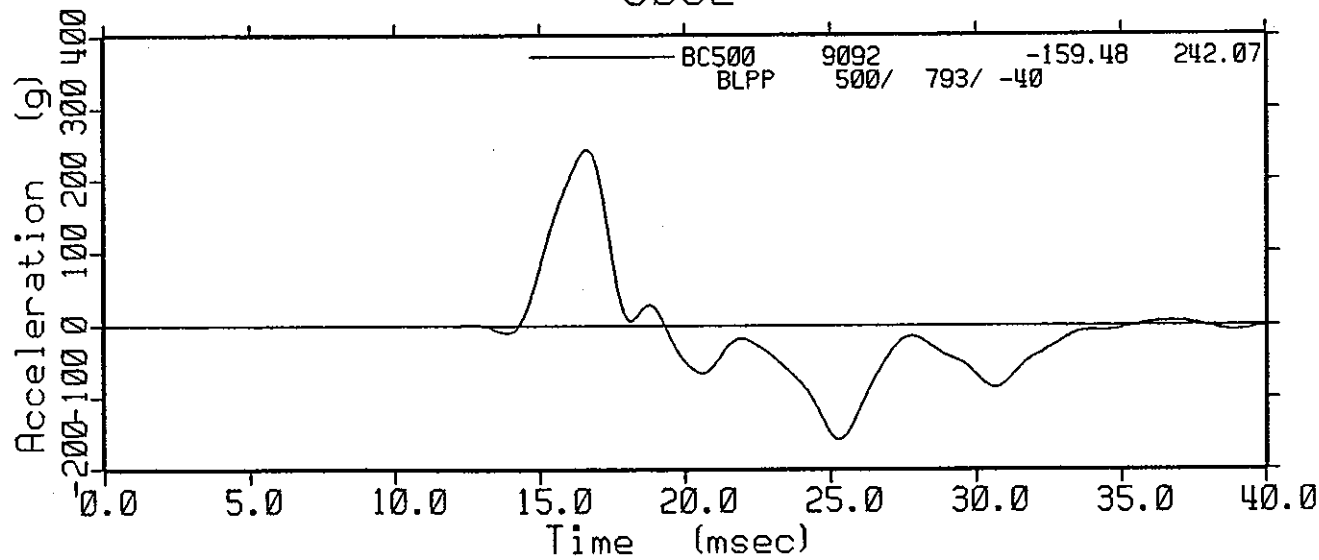

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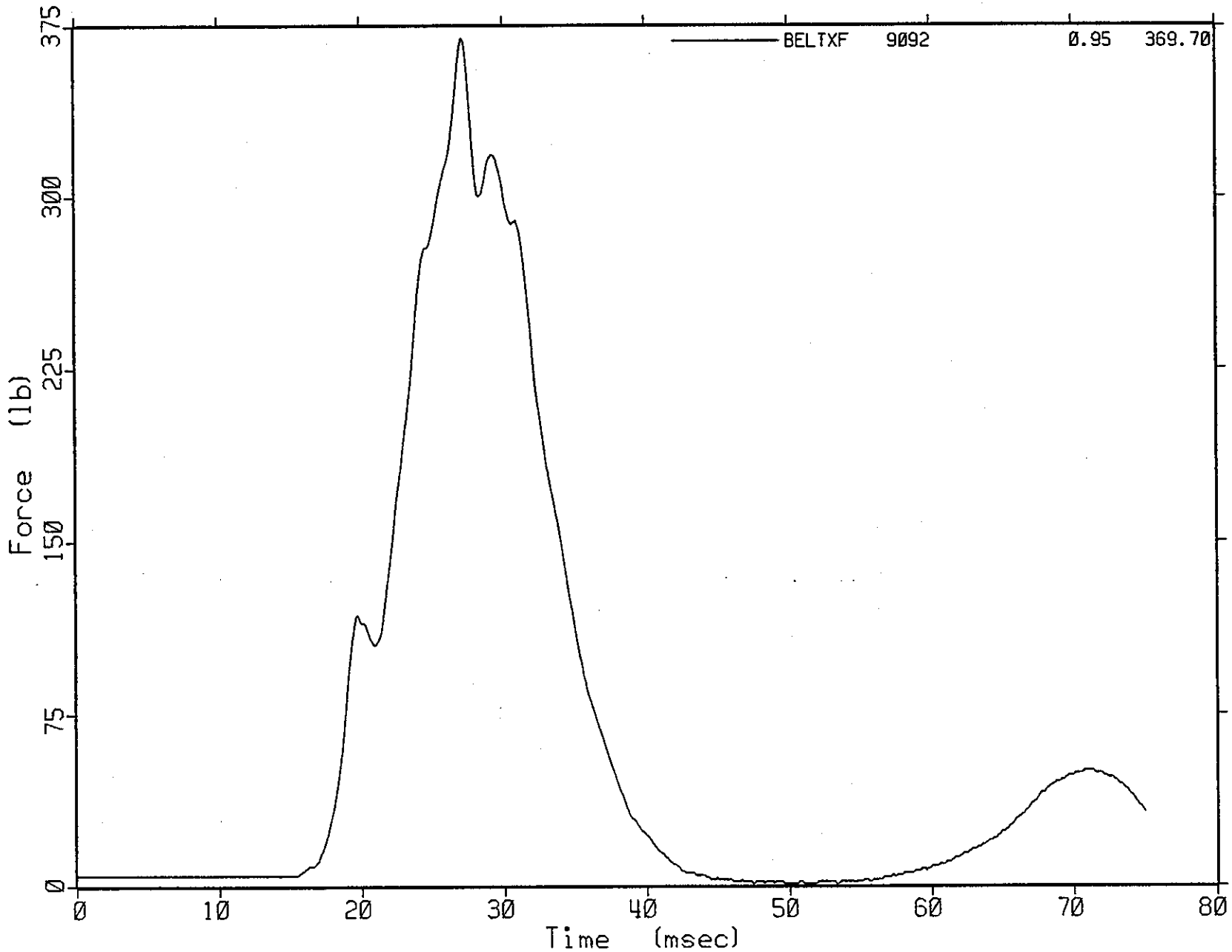

TEST 9092 - FORCE

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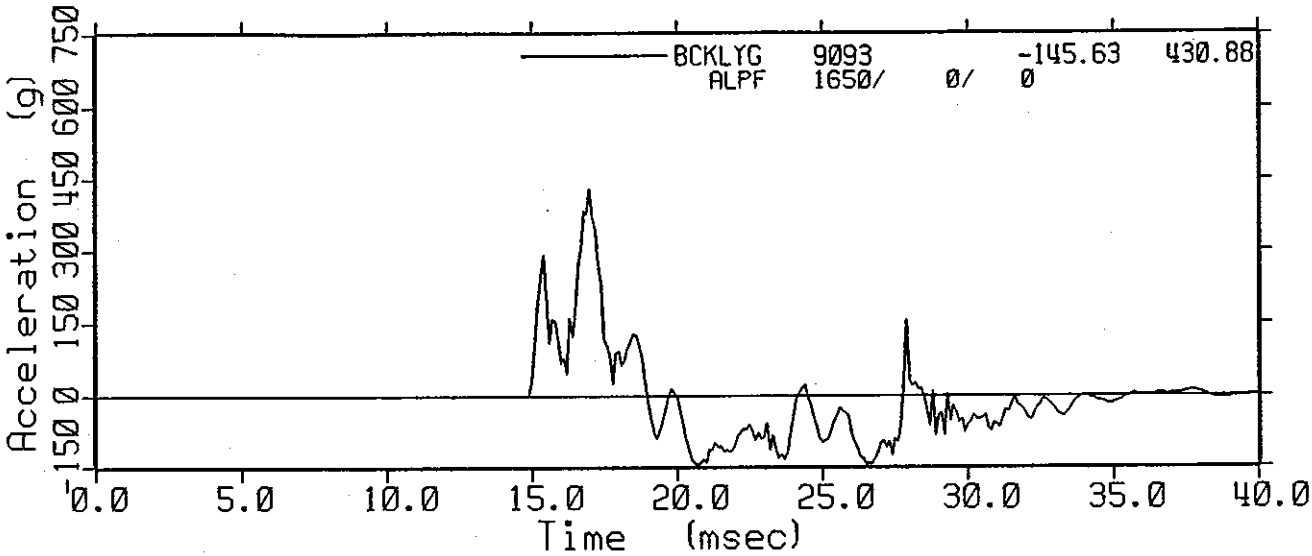

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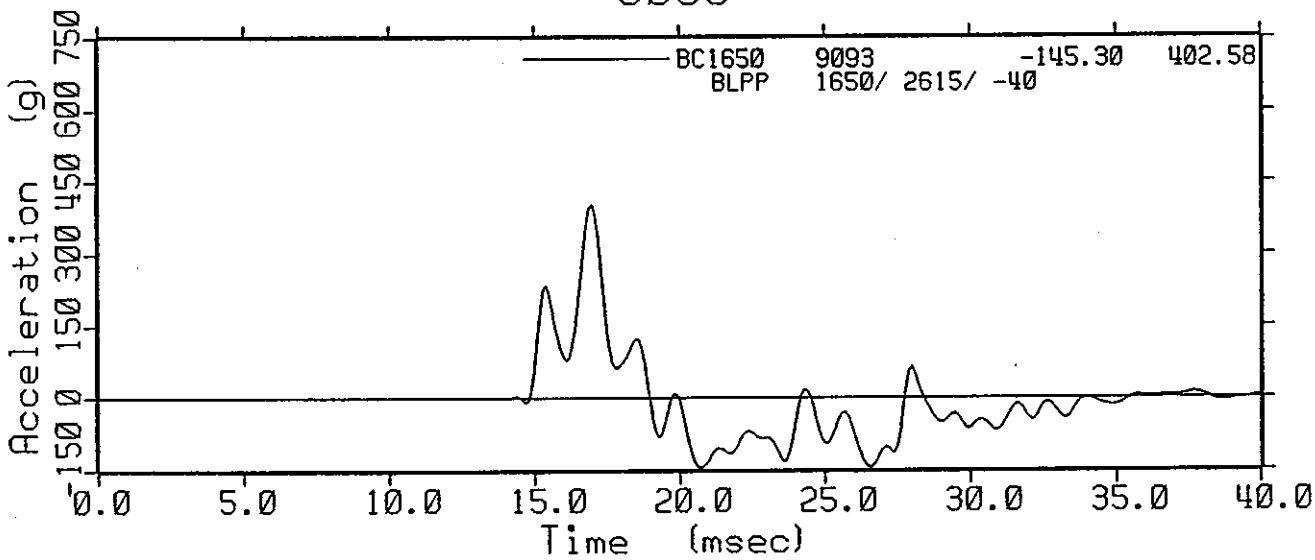

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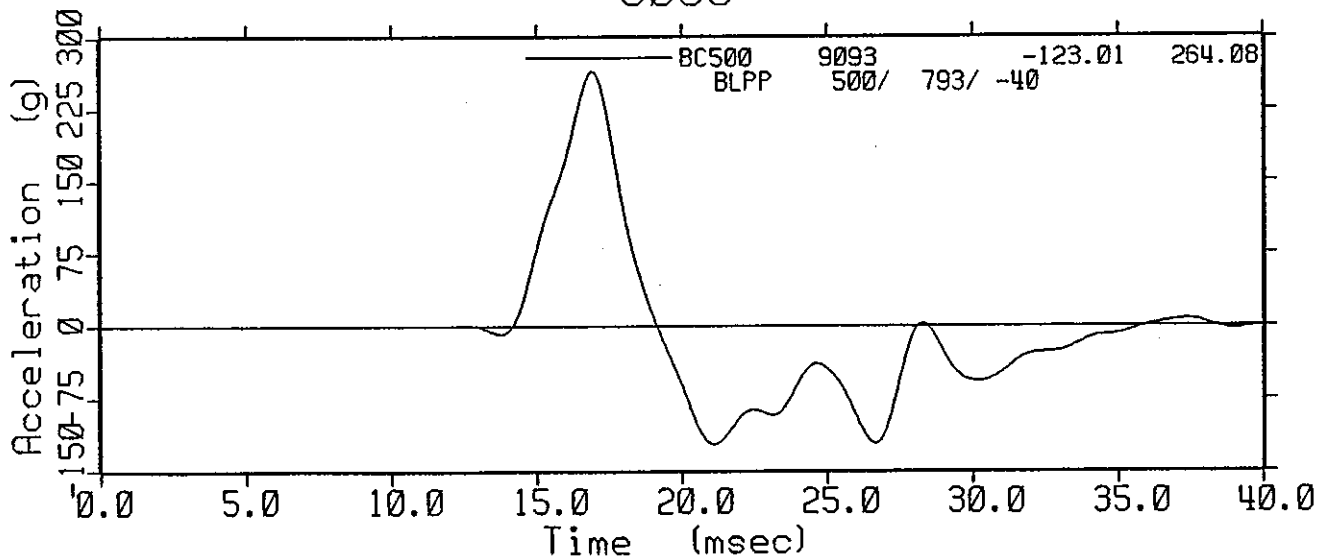

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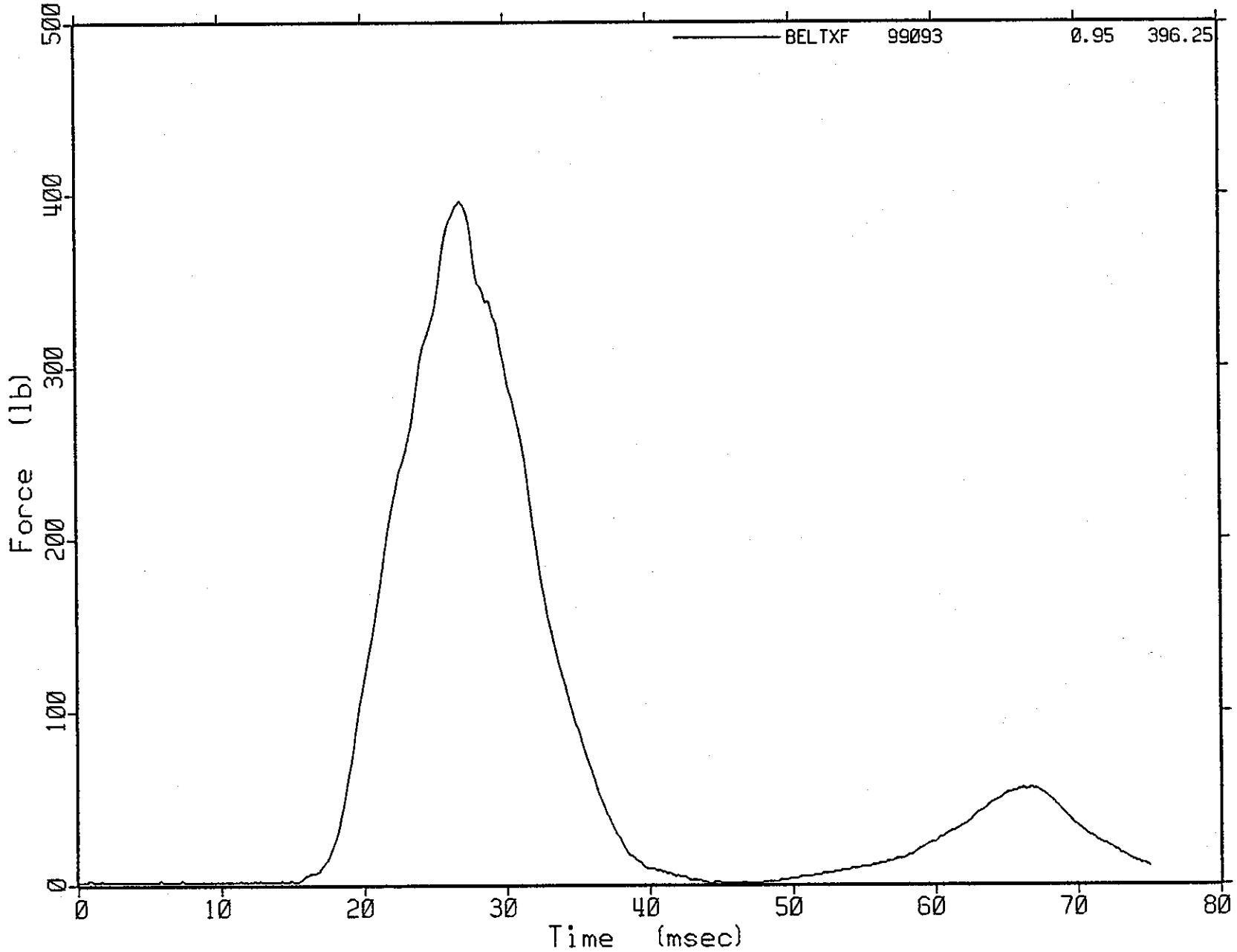

TEST 9093 - FORCE

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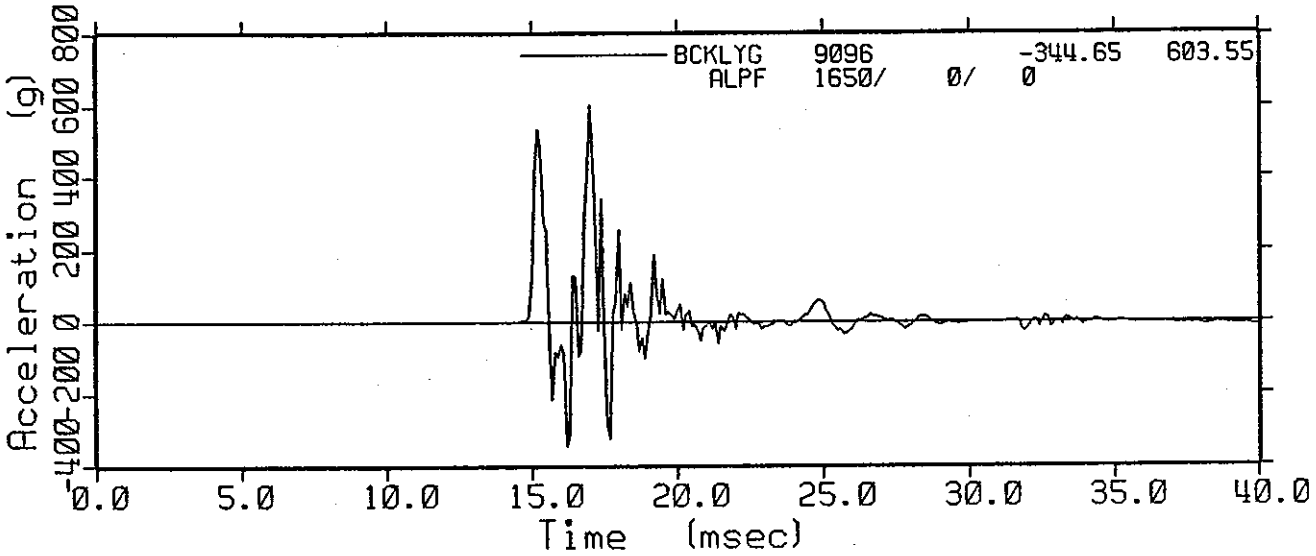

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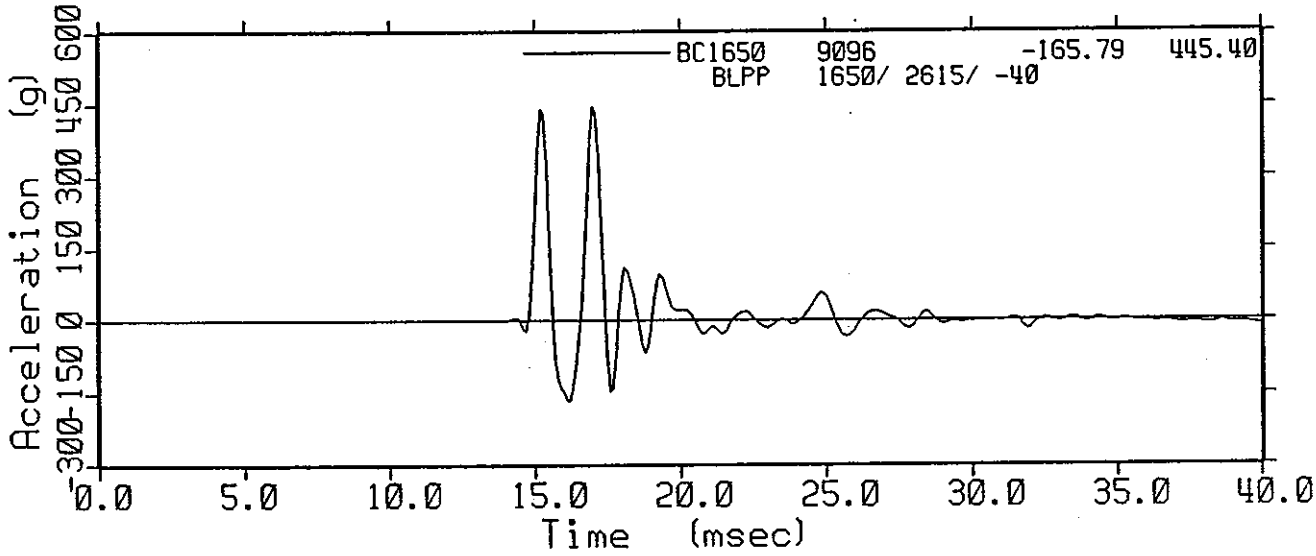

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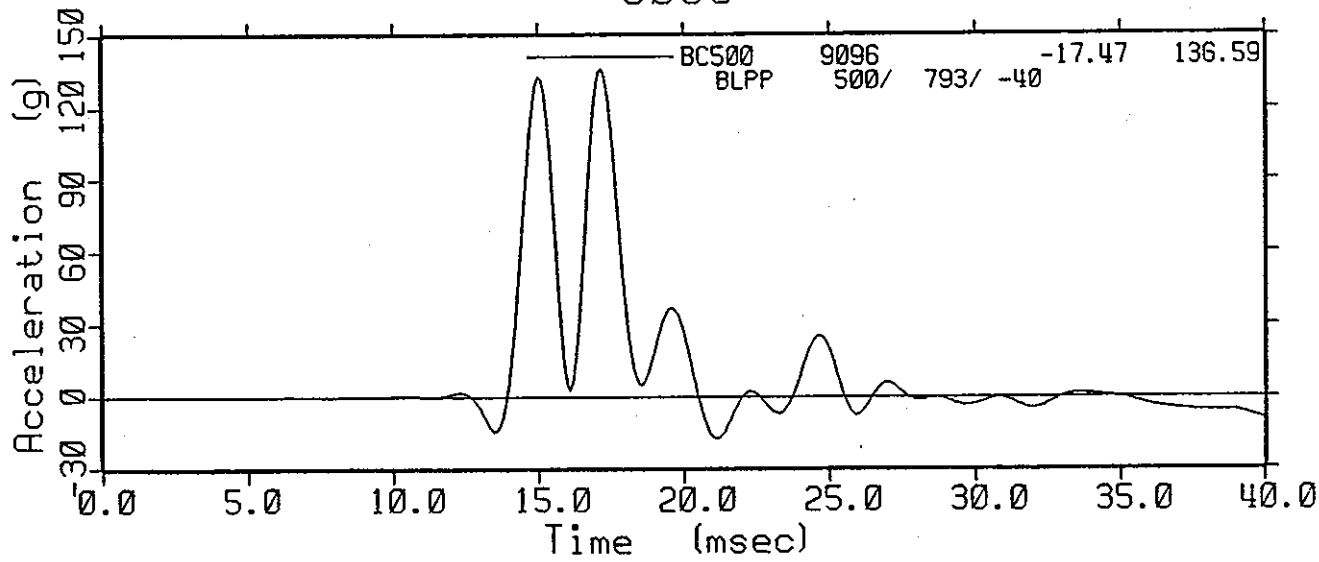

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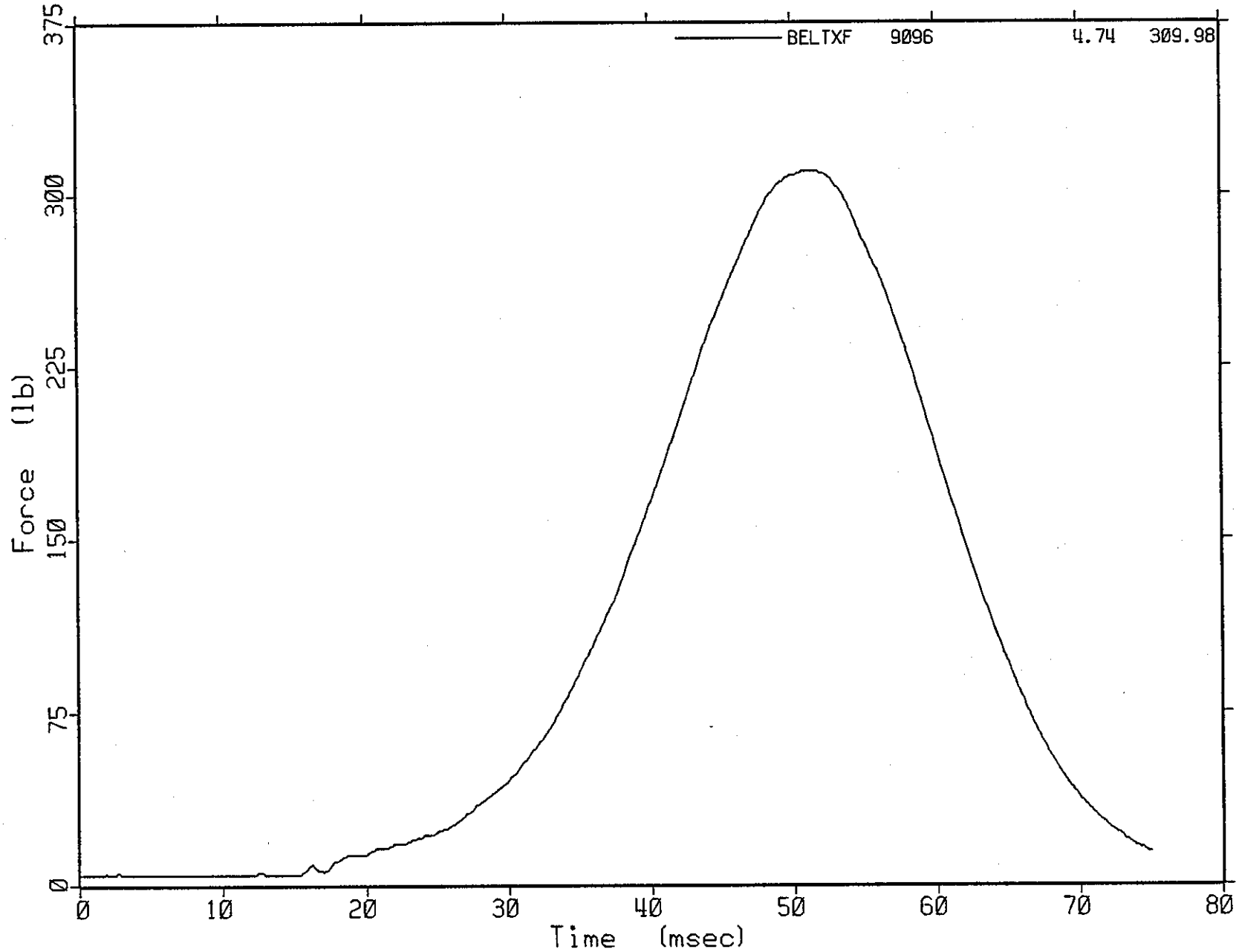

TEST 9096 - FORCE

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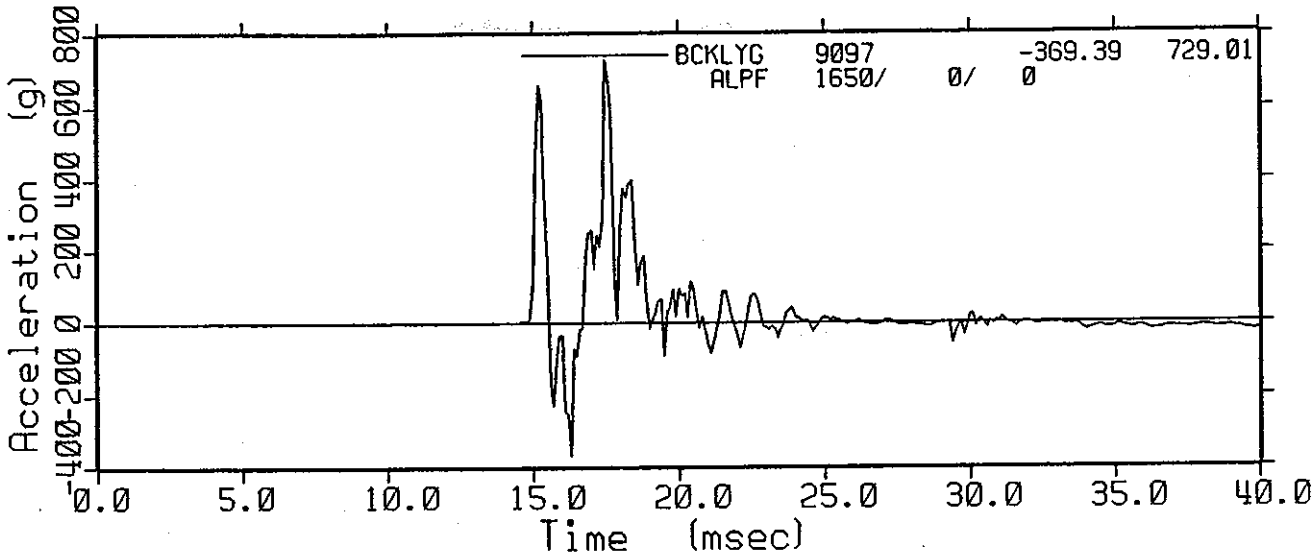

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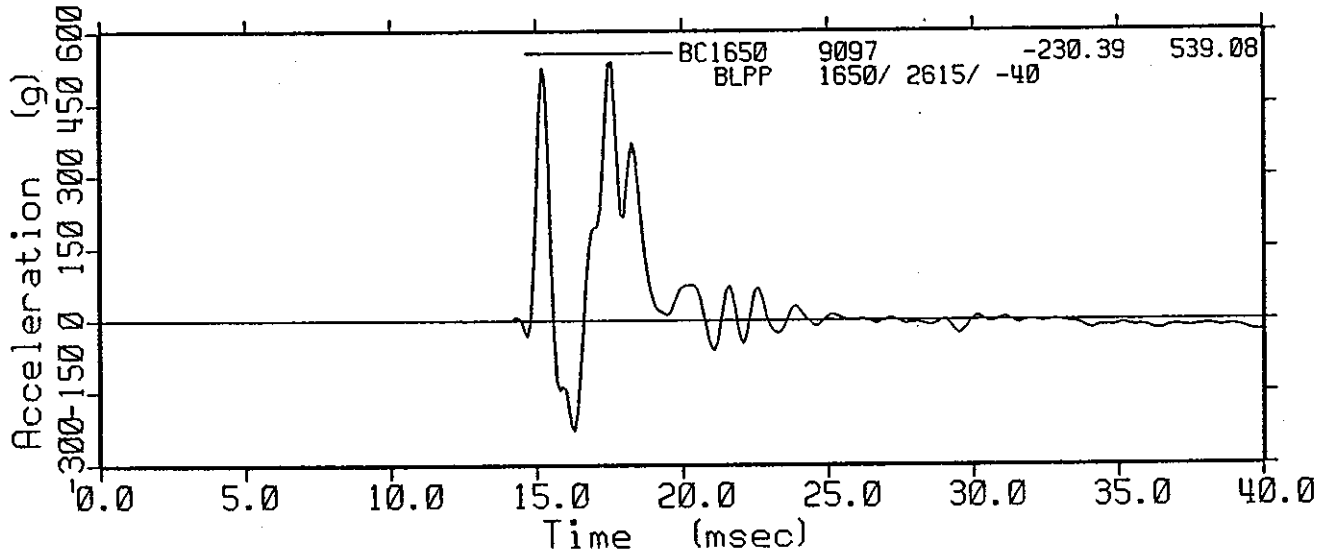

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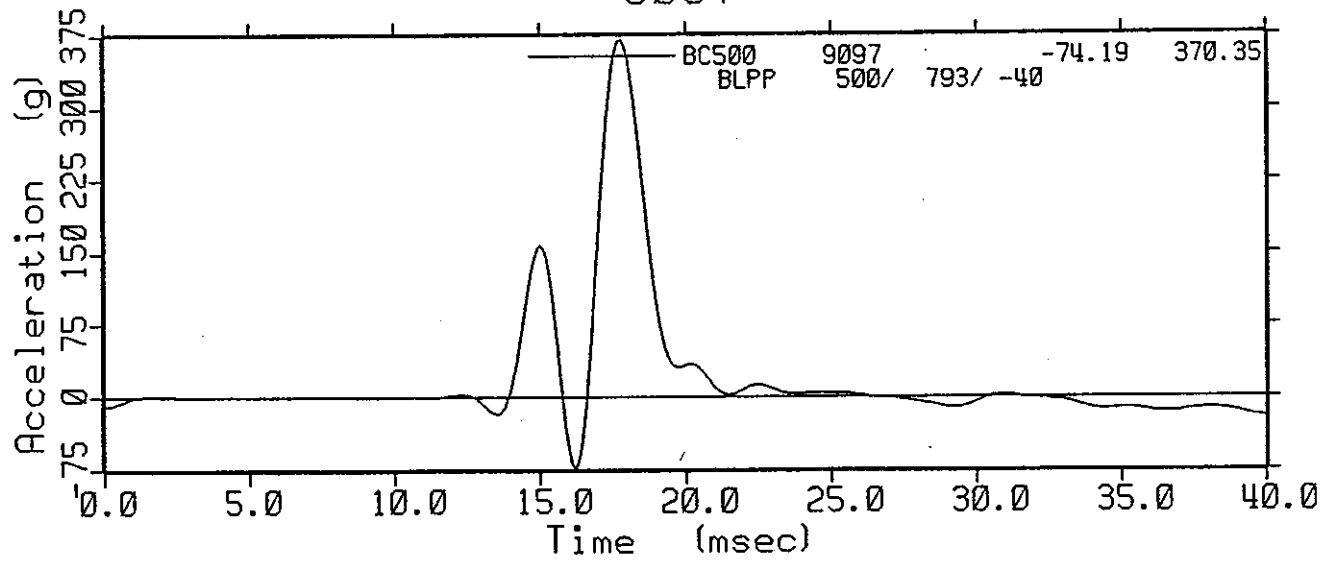

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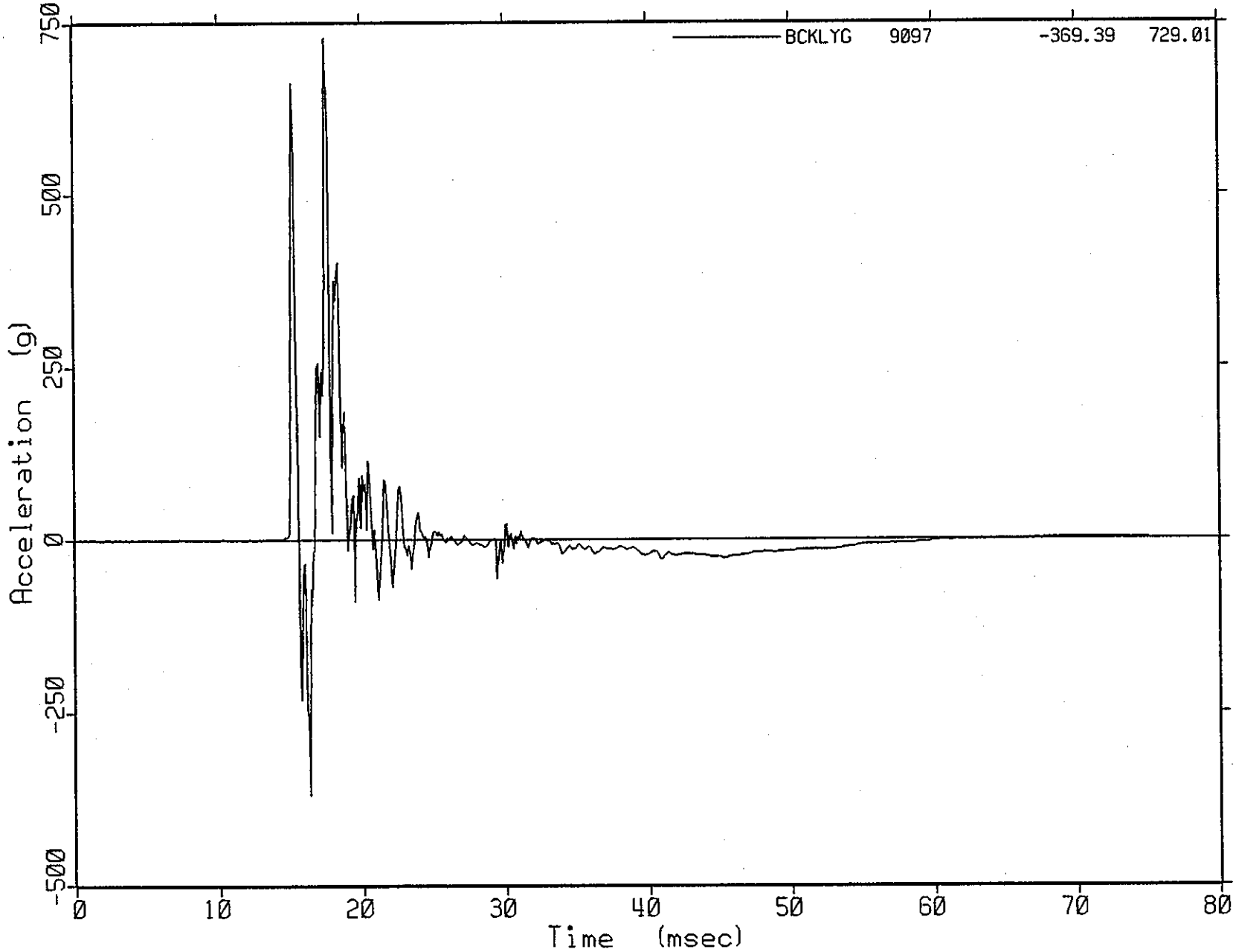

TEST 9097 - ACCELERATION

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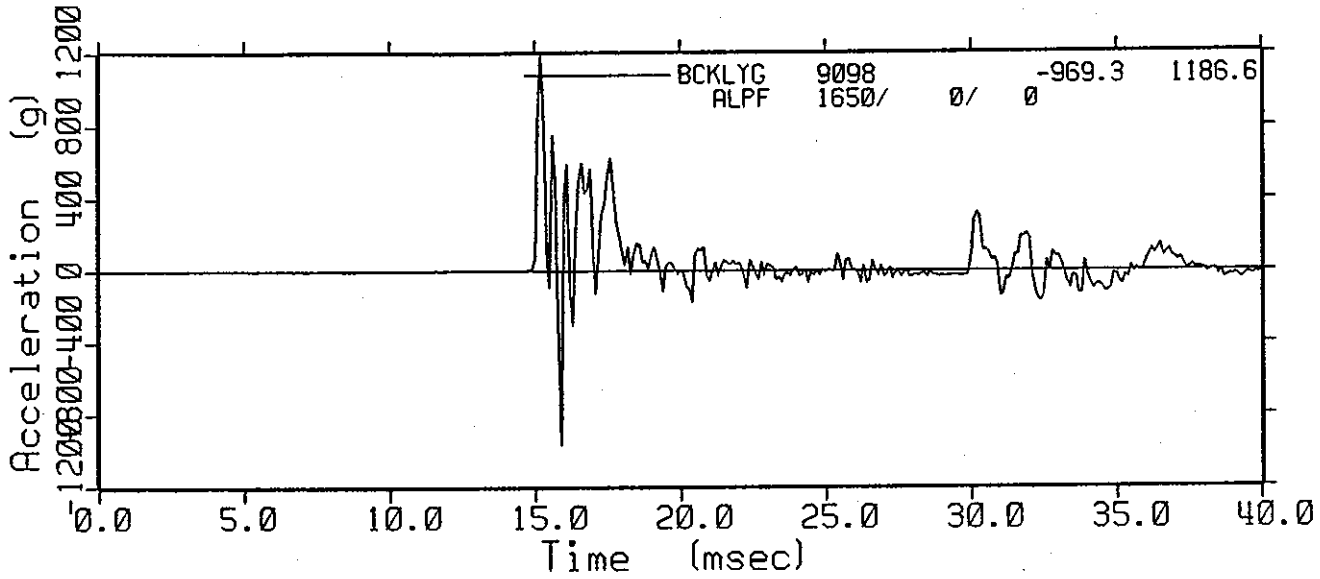

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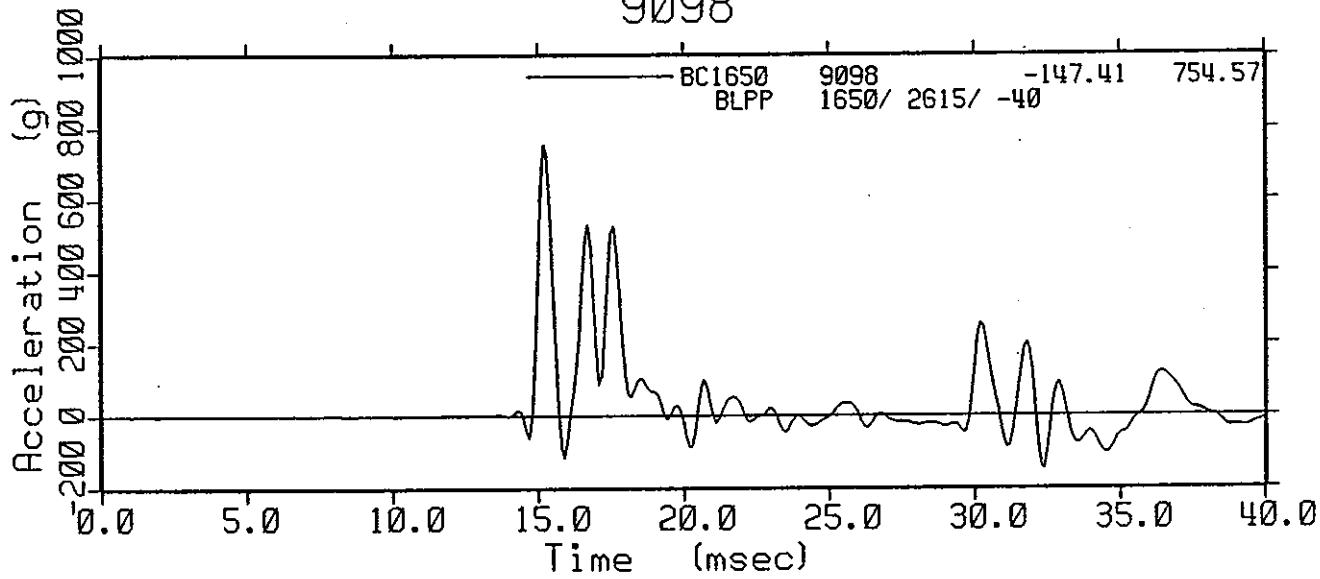

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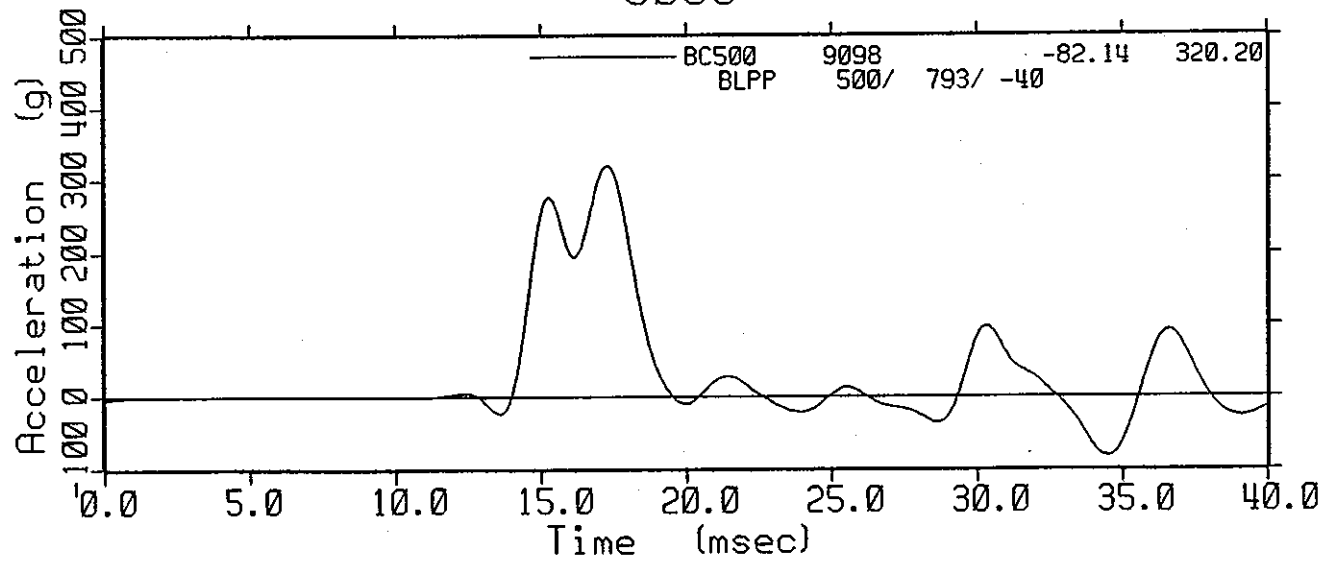

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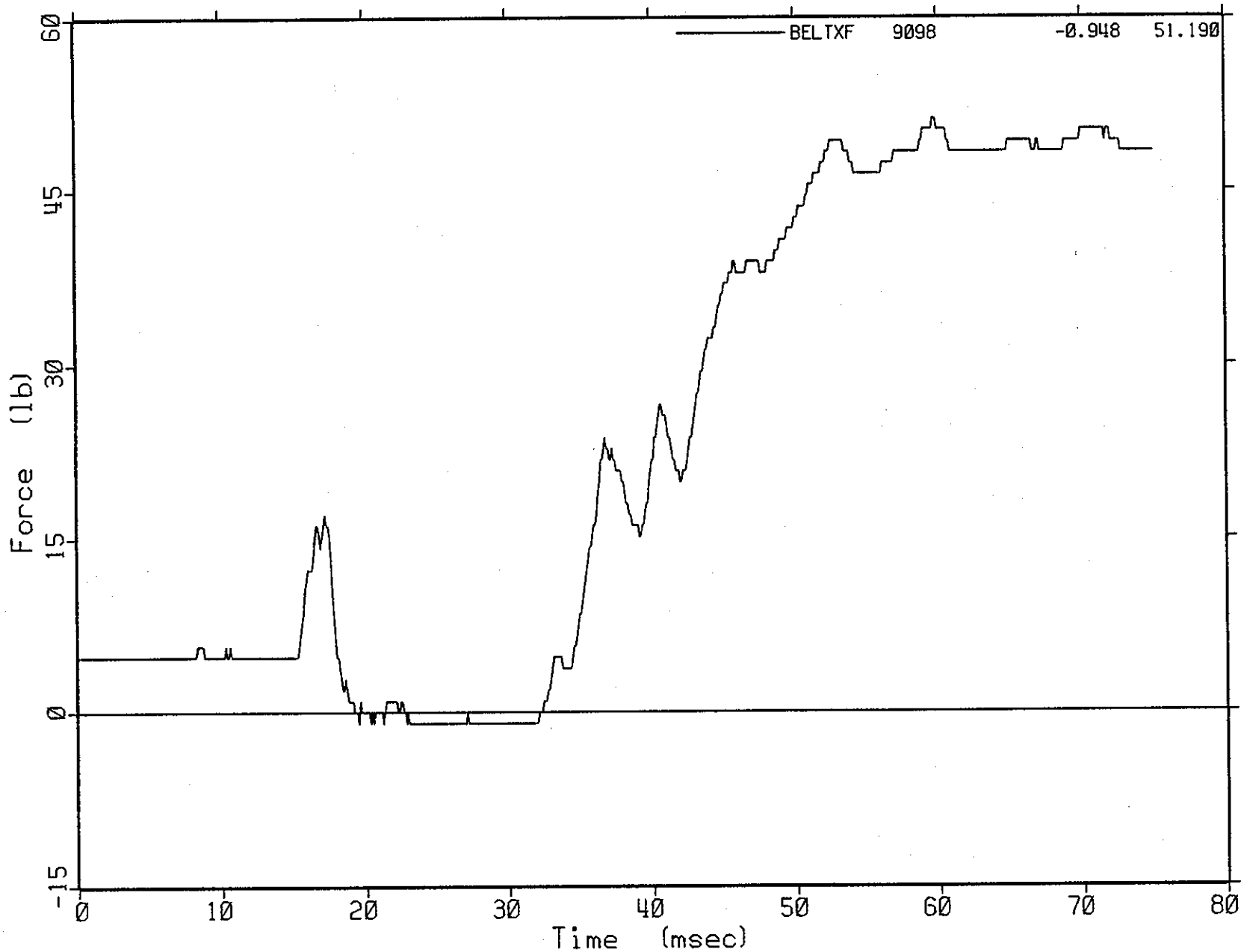

TEST 9098 - FORCE

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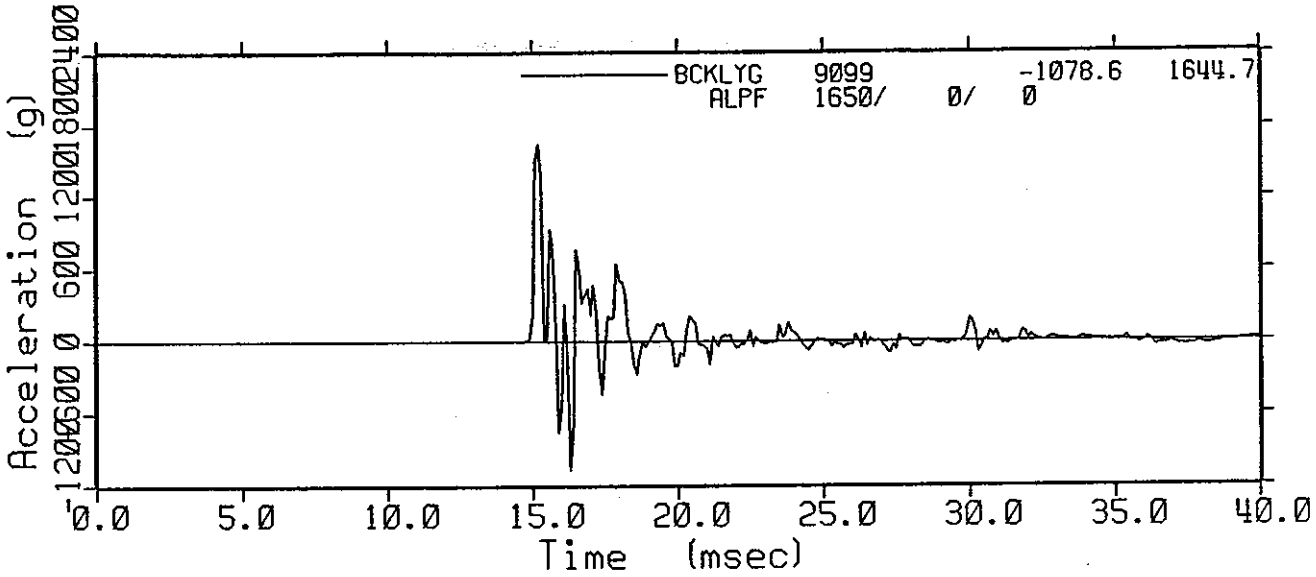

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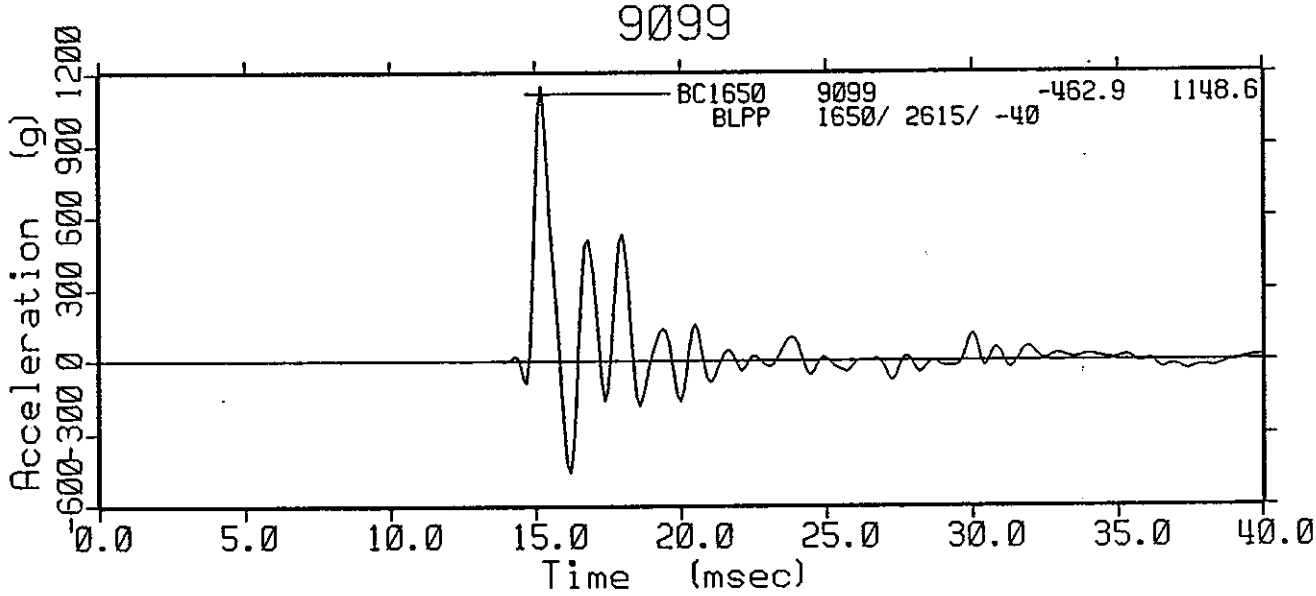

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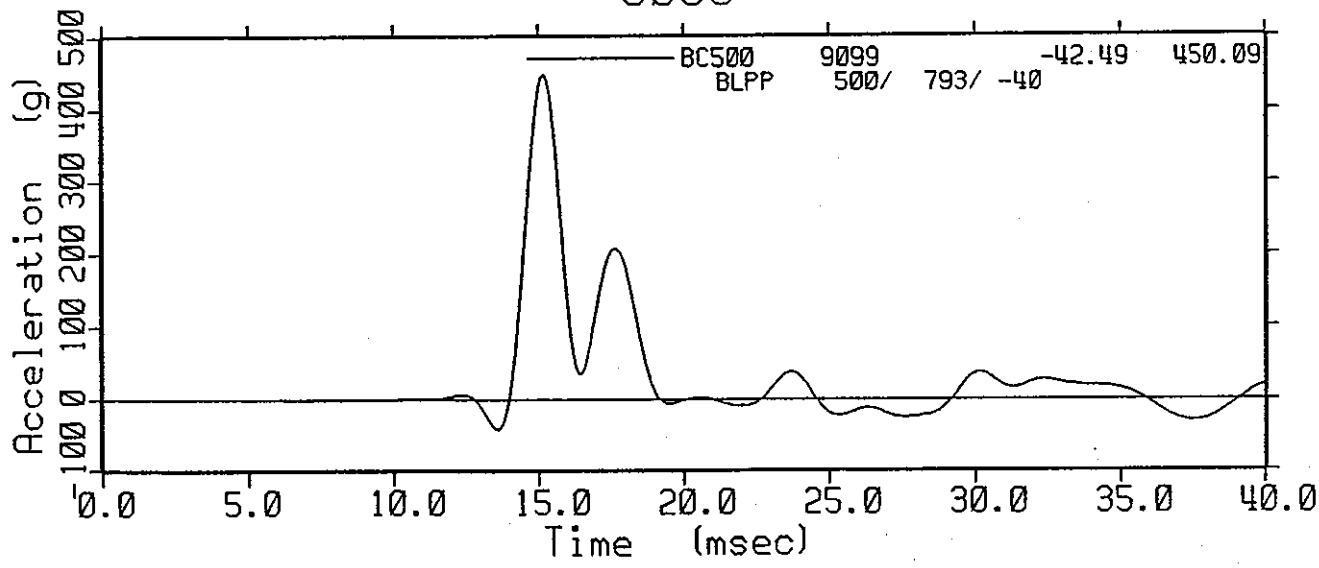

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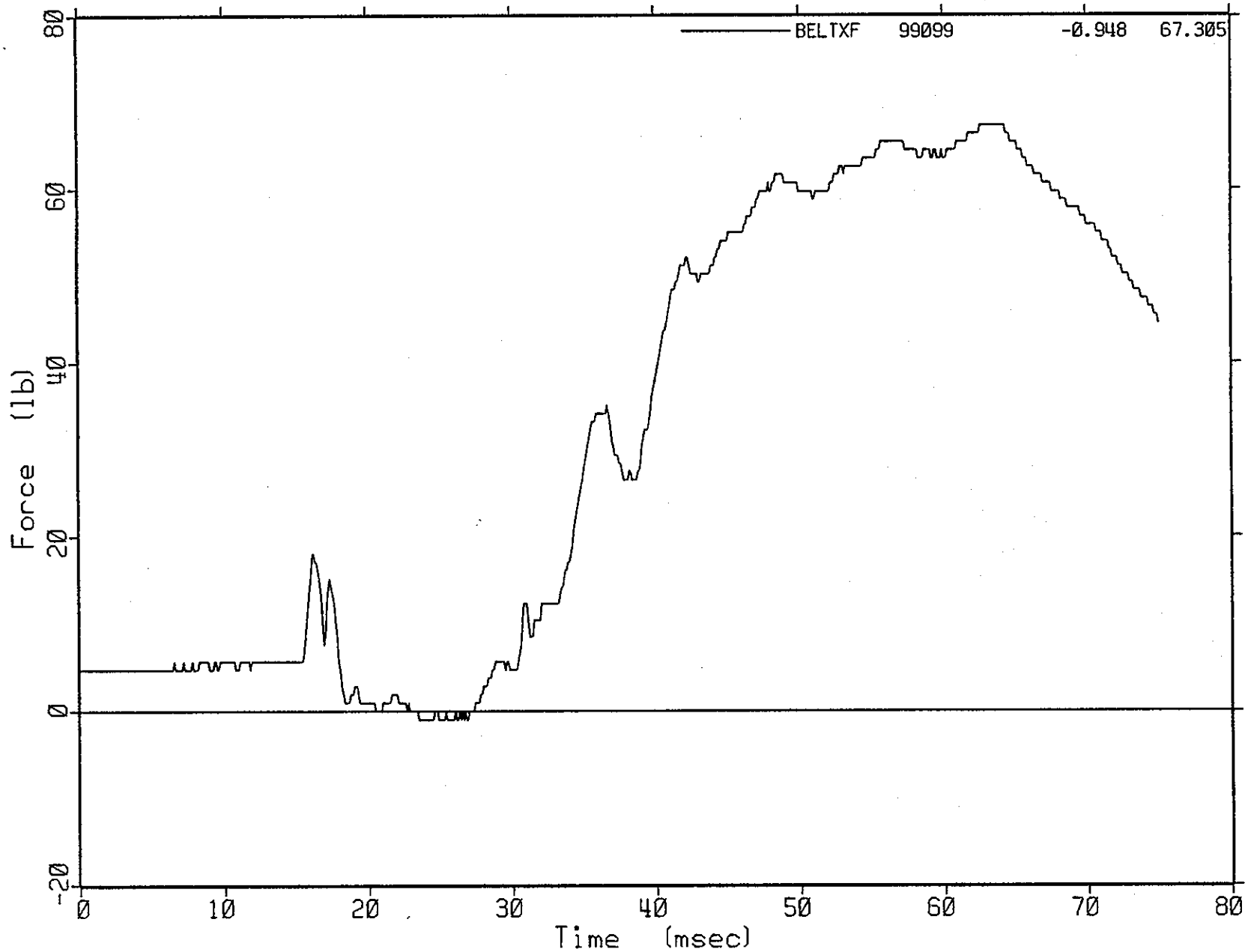

TEST 9099 - FORCE

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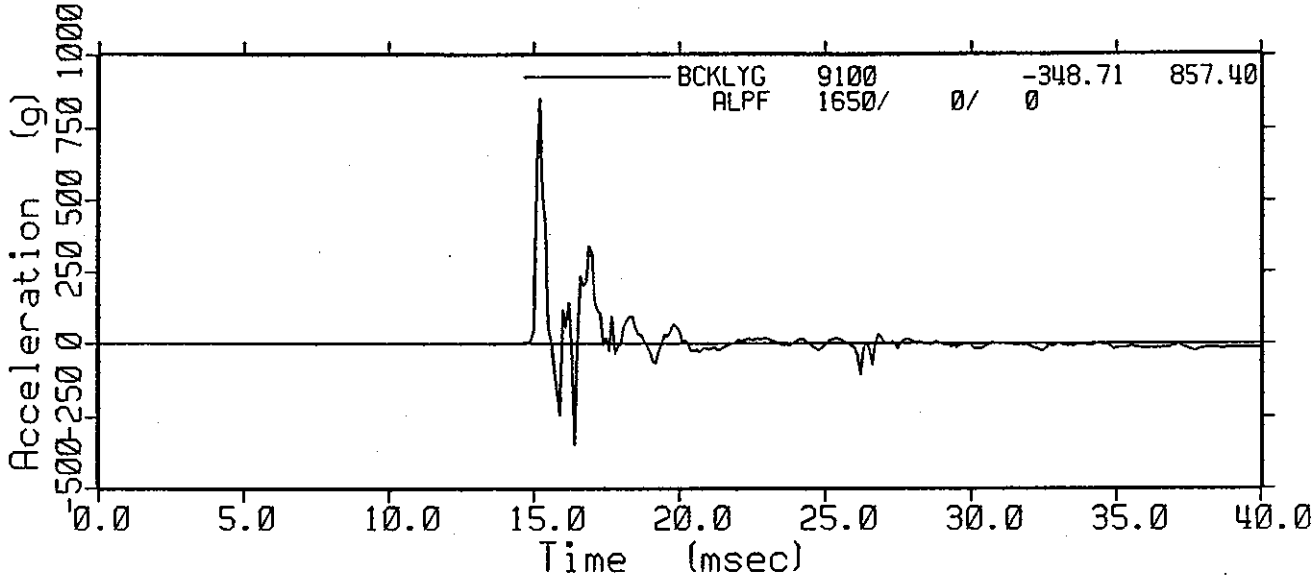

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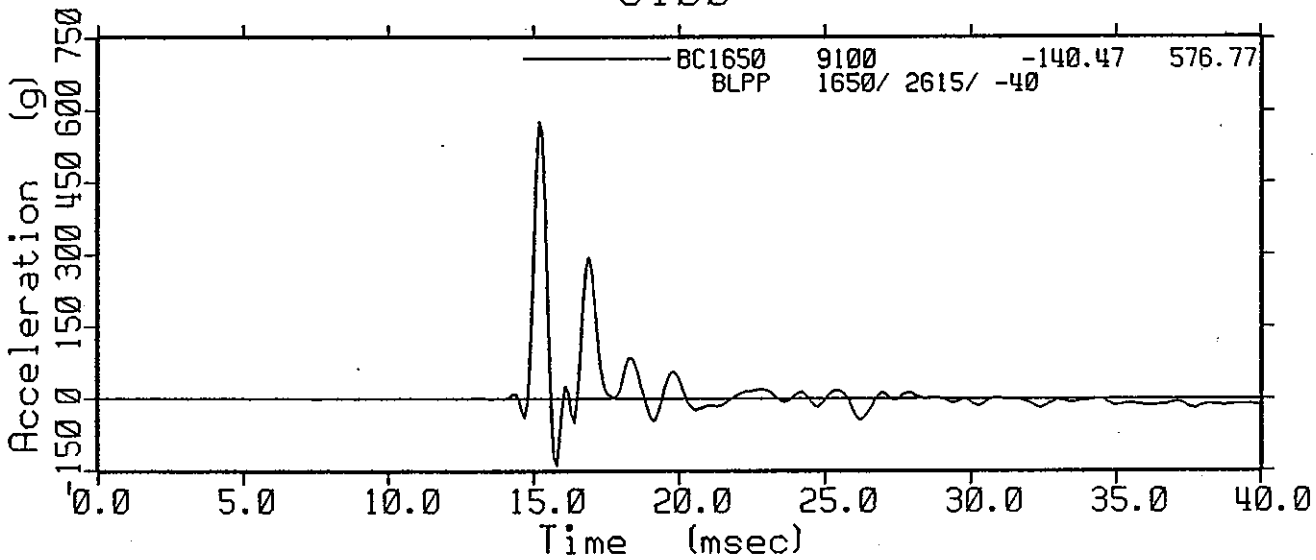

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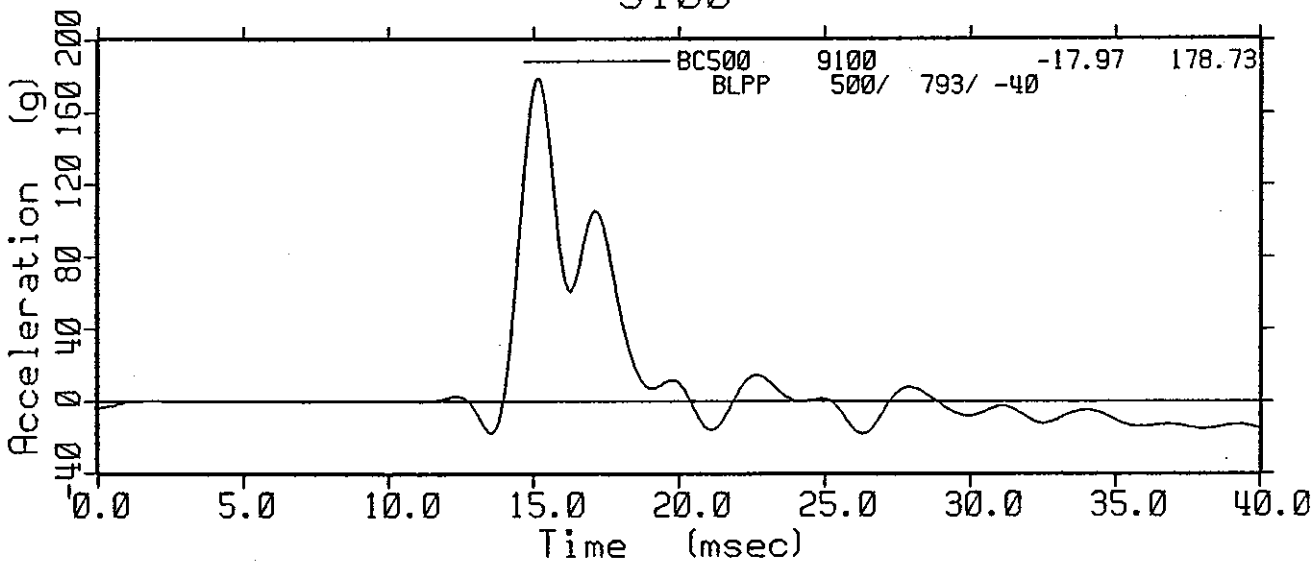

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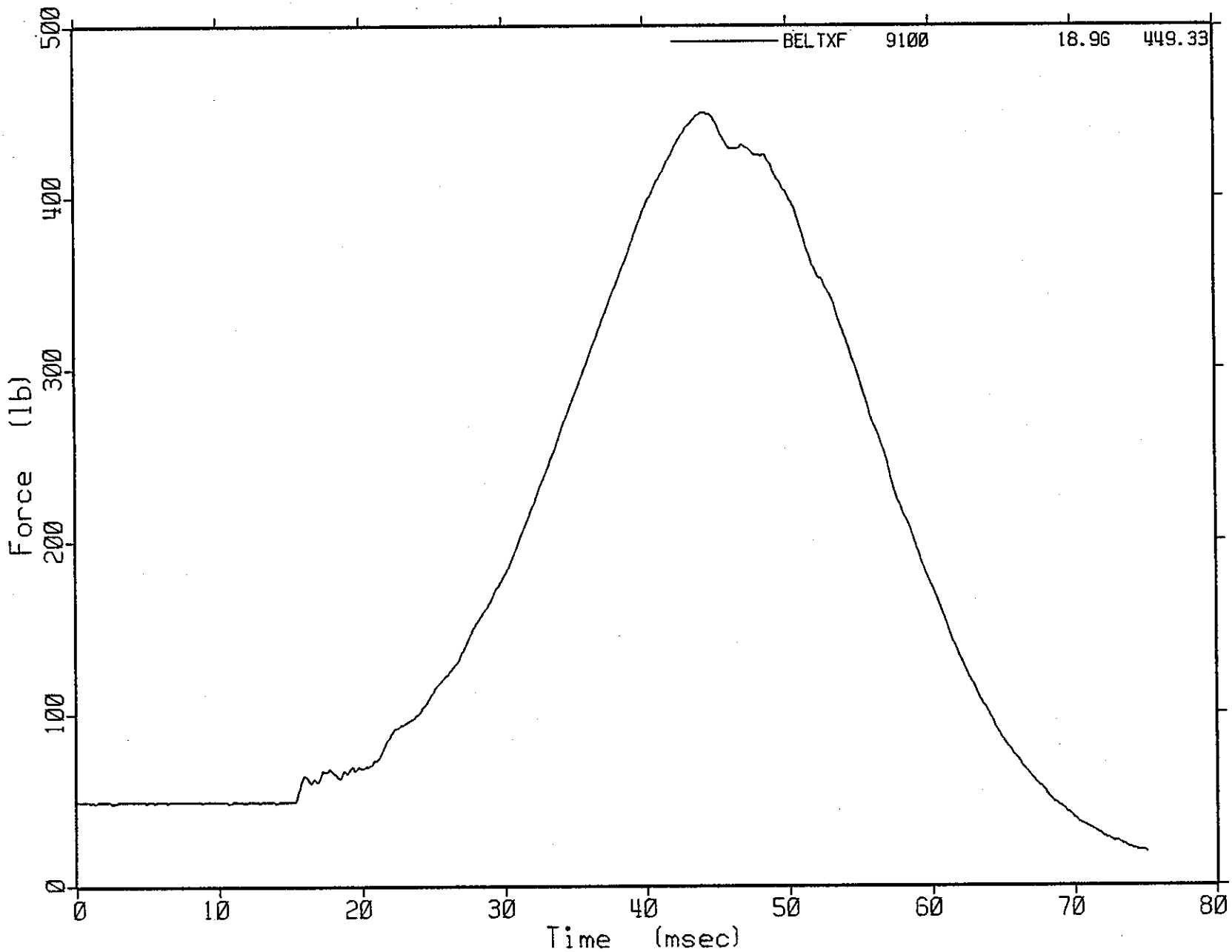

TEST 9100 - FORCE

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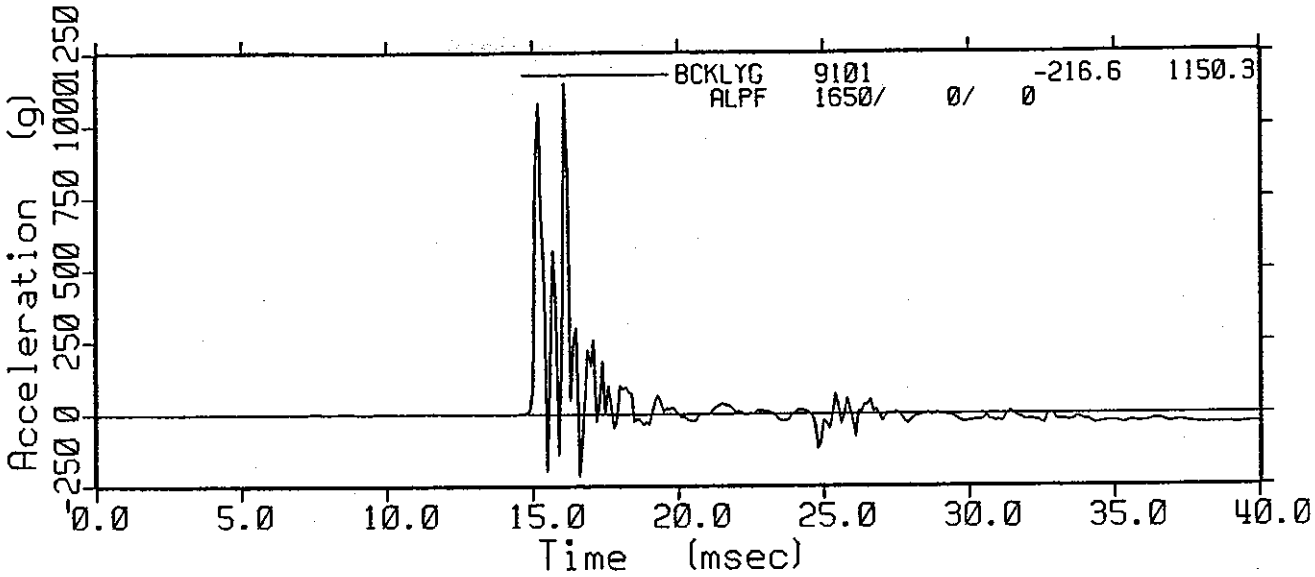

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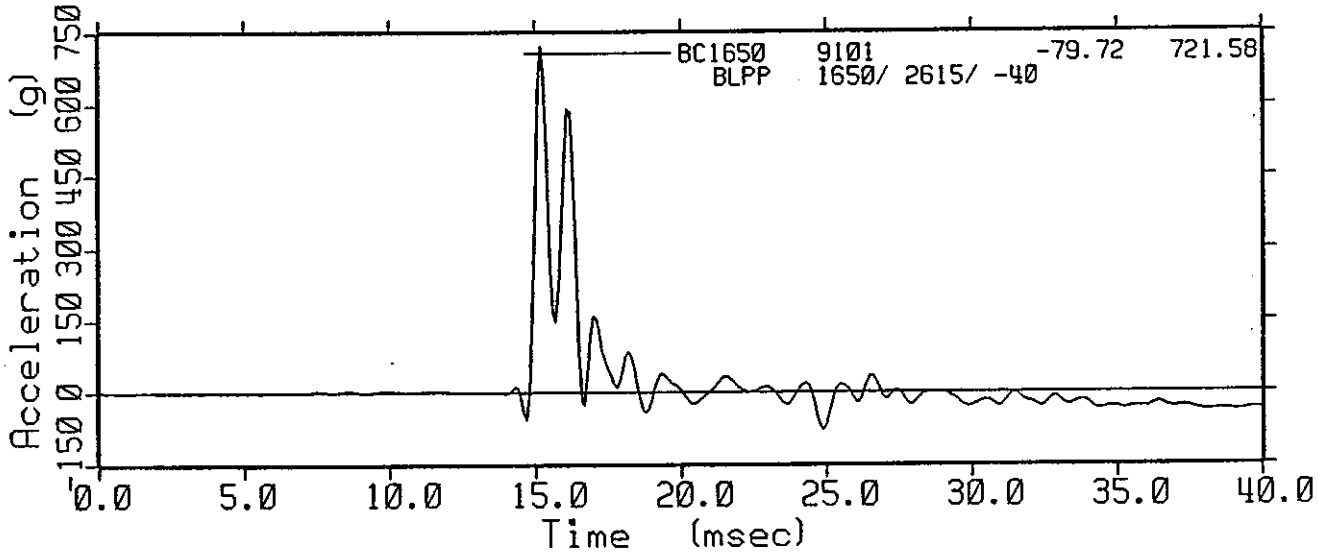

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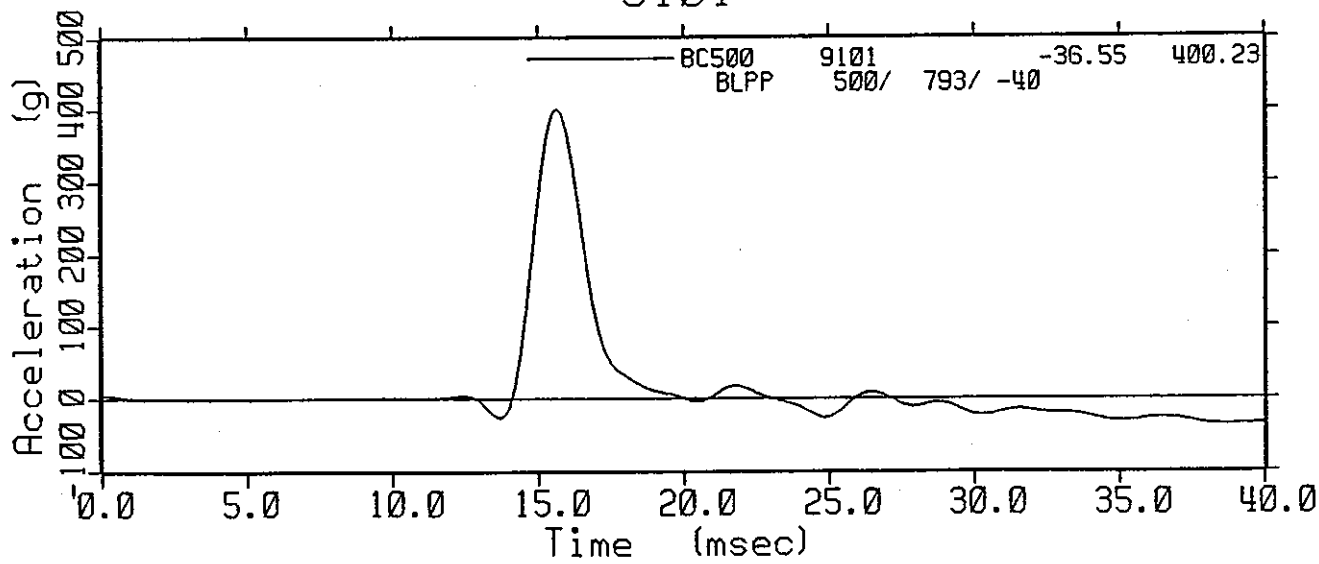

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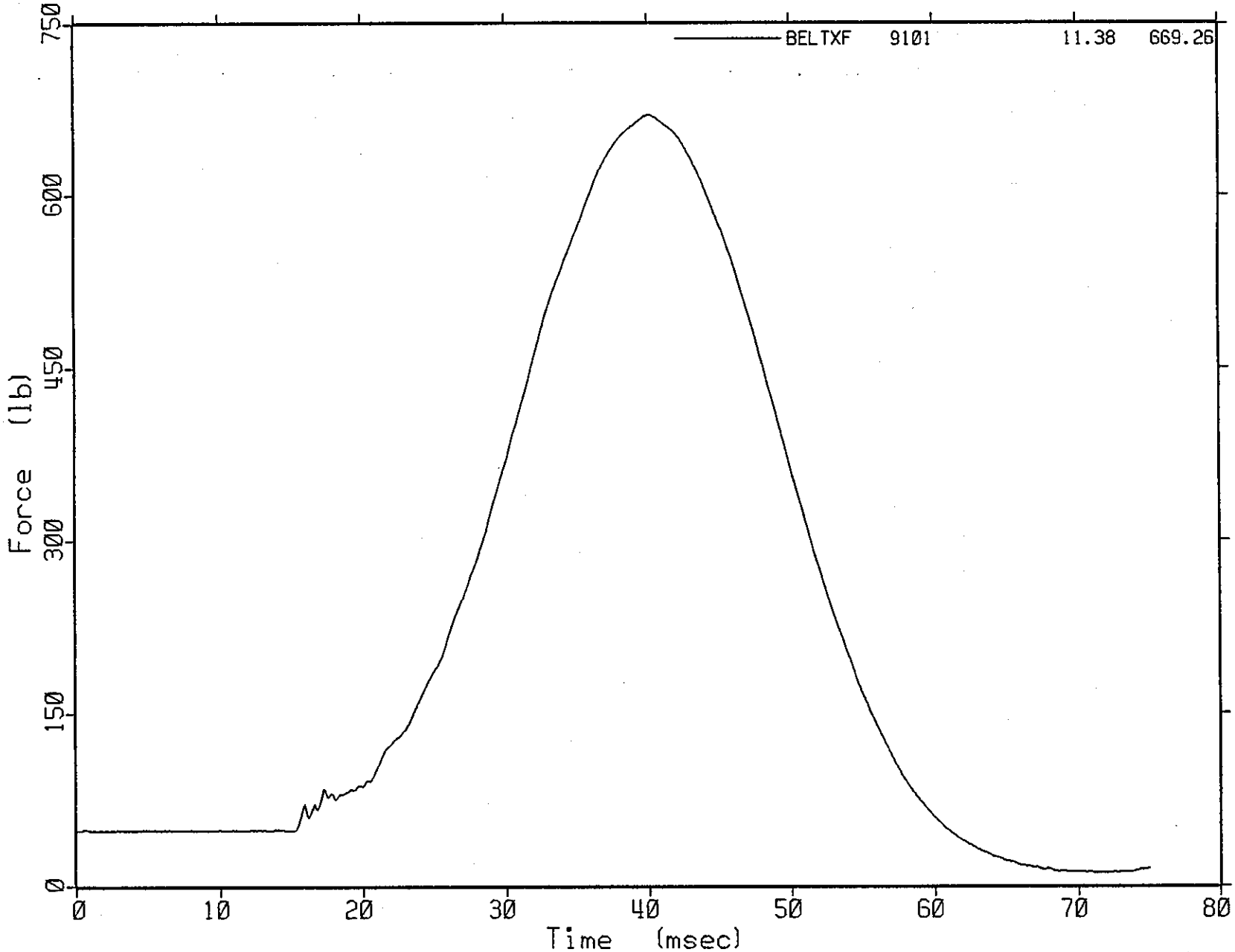
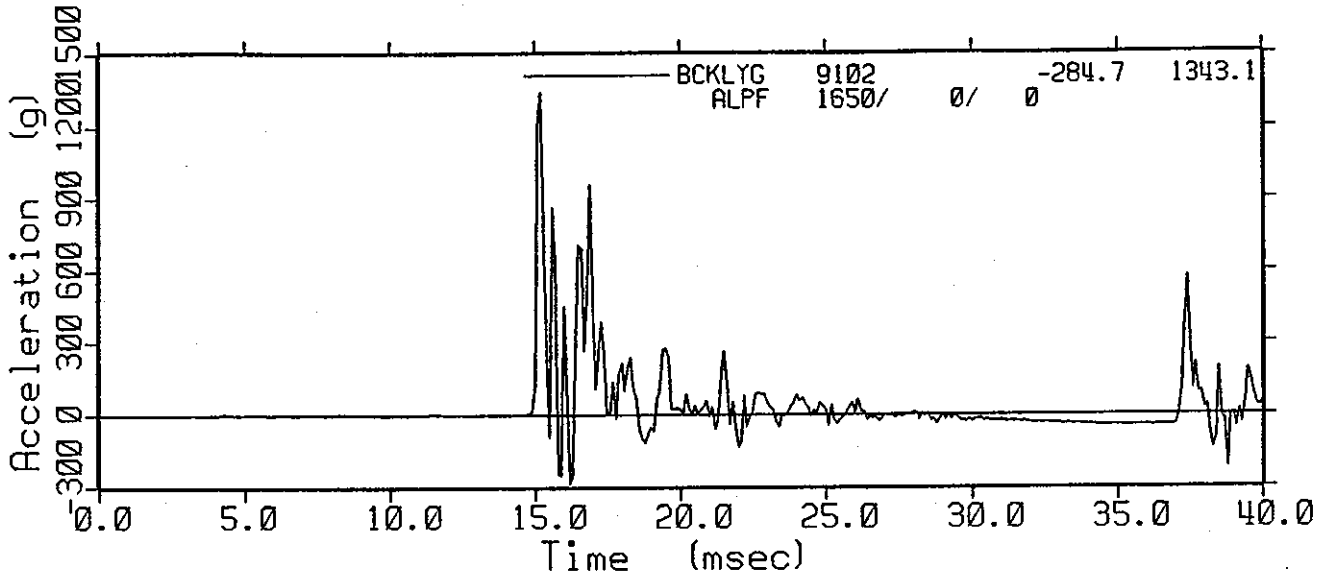


TEST 9101 - FORCE

8-OCT-92 20:25



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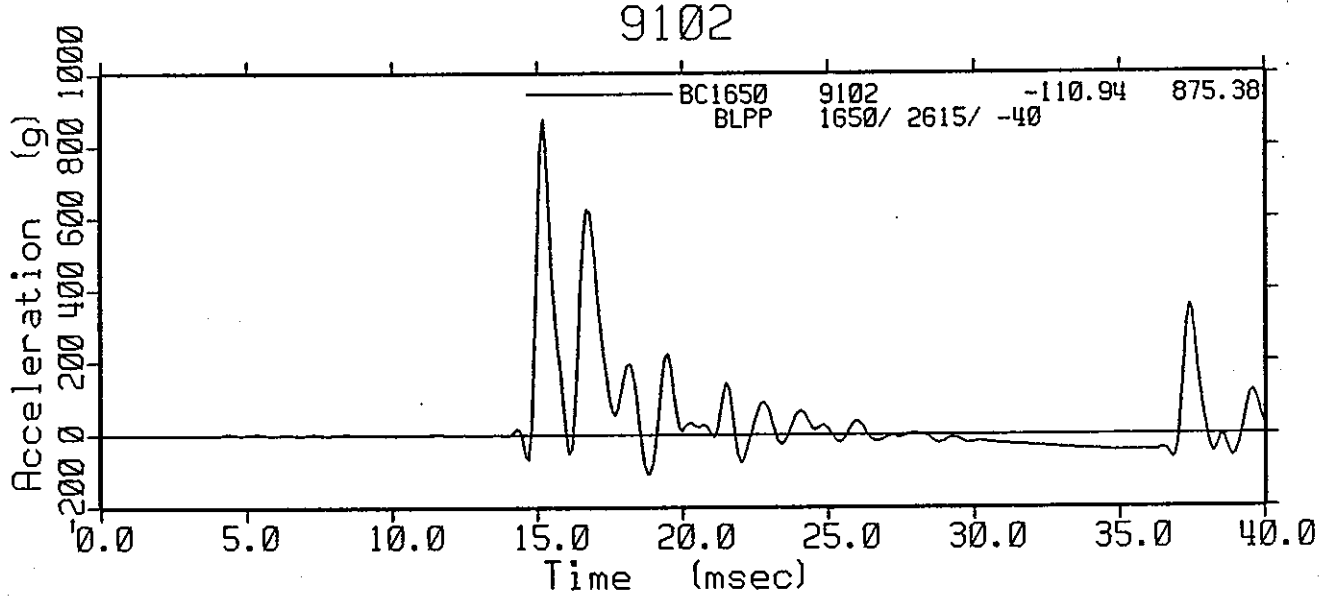

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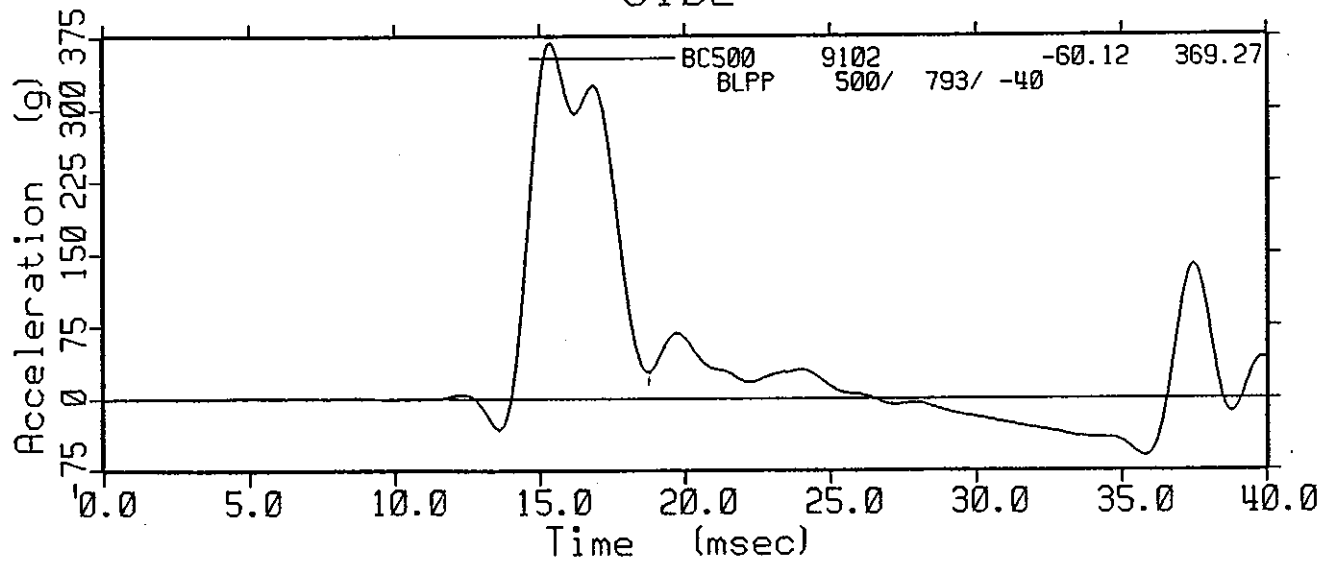
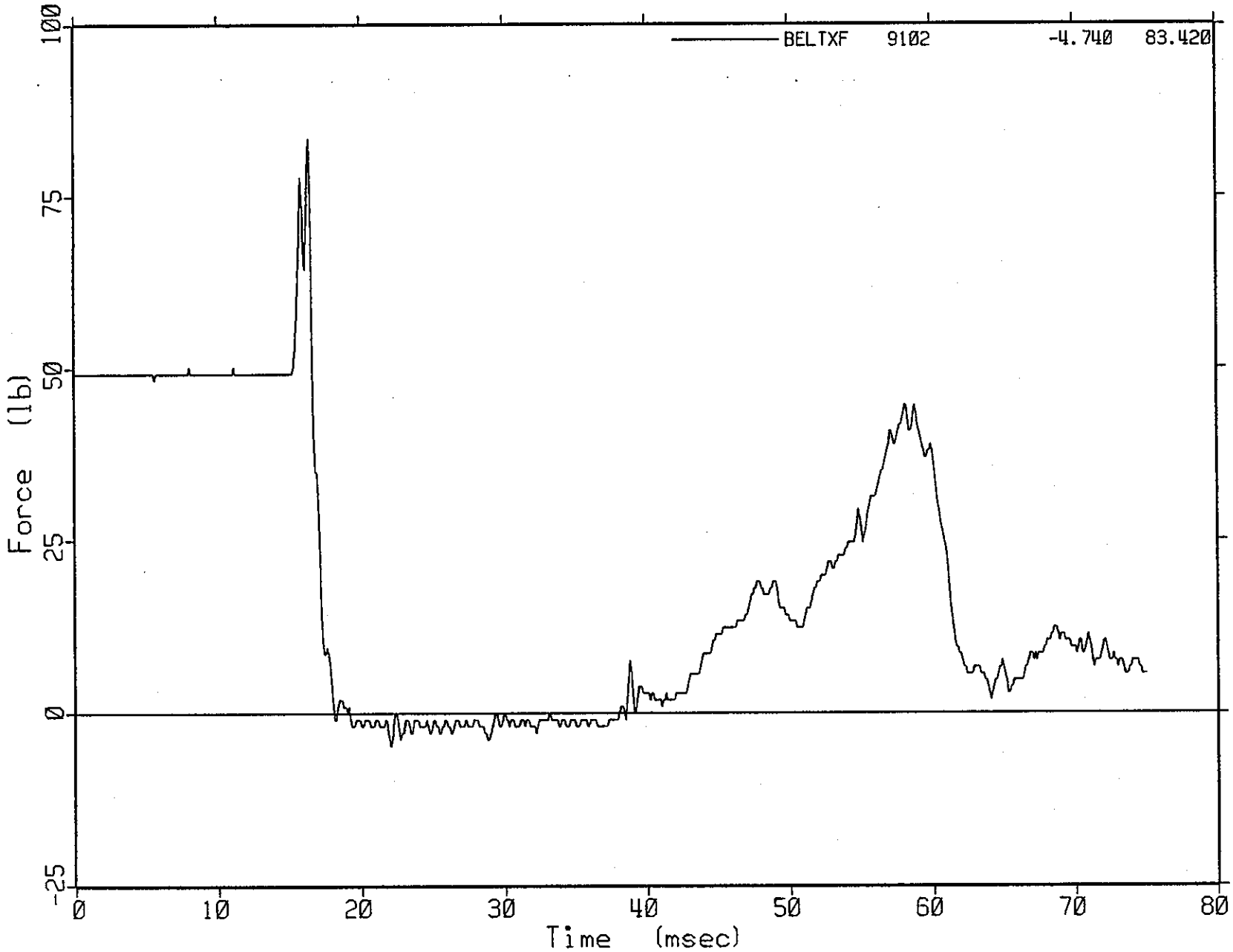


9102

8-OCT-92 18:42



TEST 9102 - FORCE

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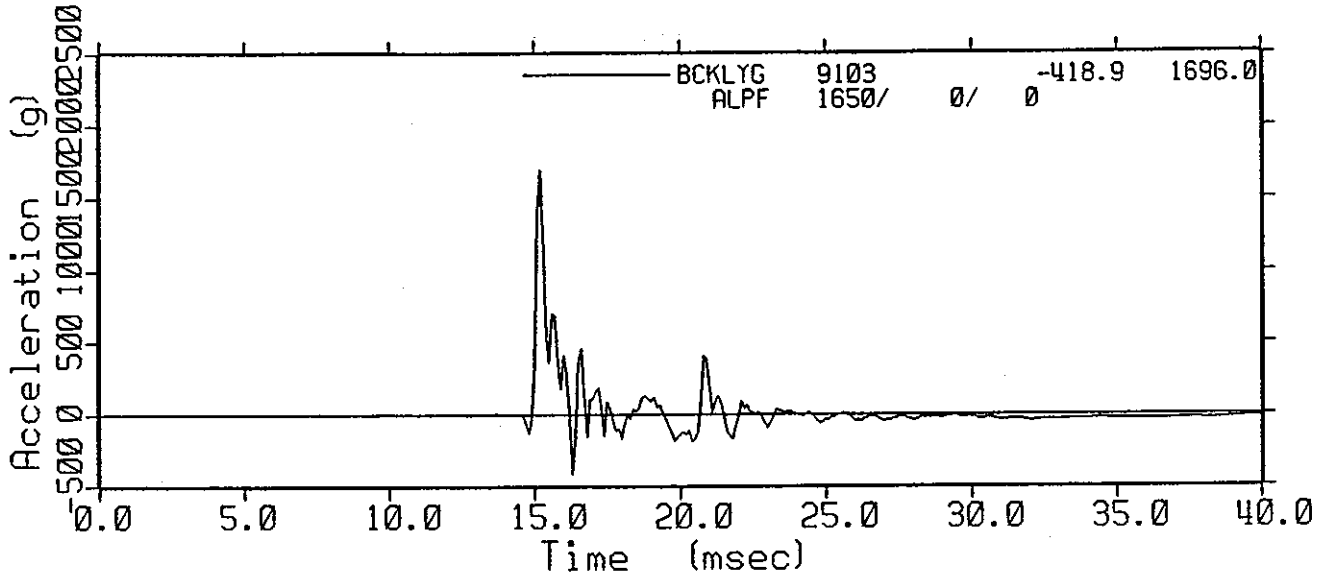

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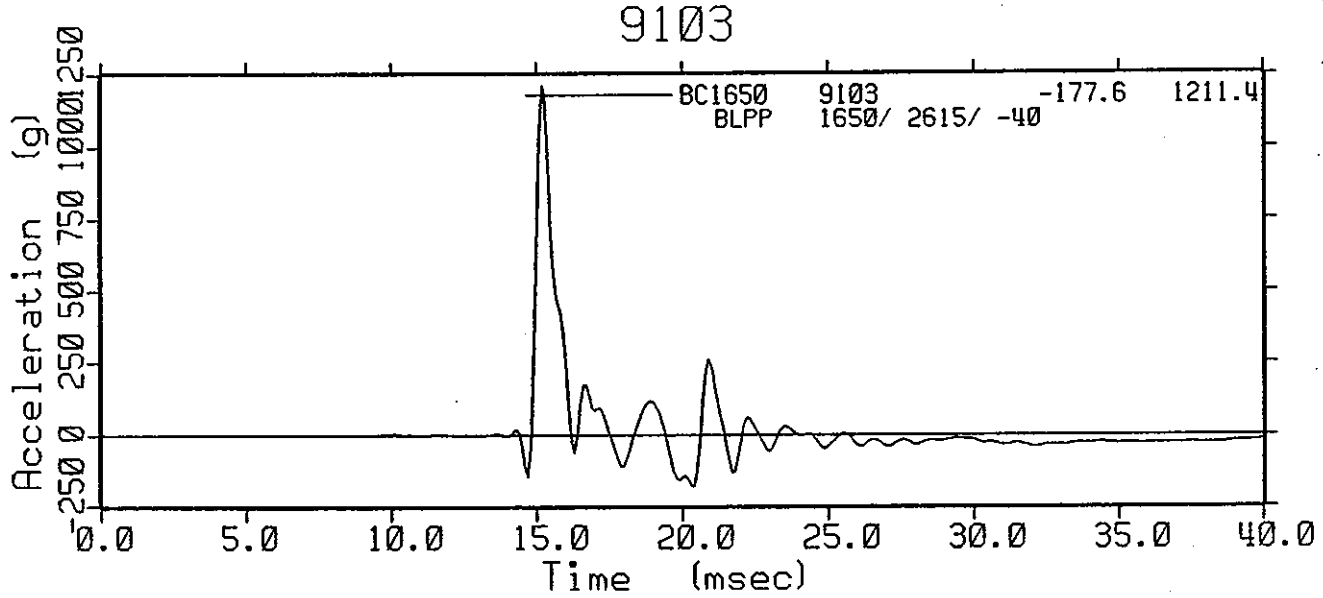

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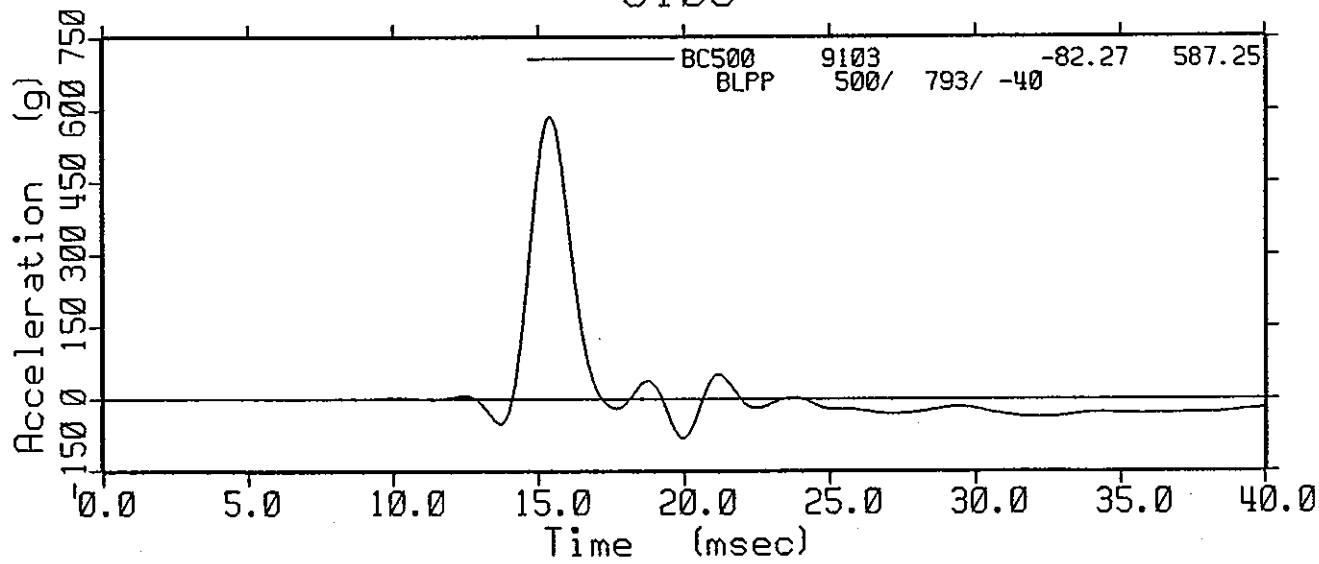
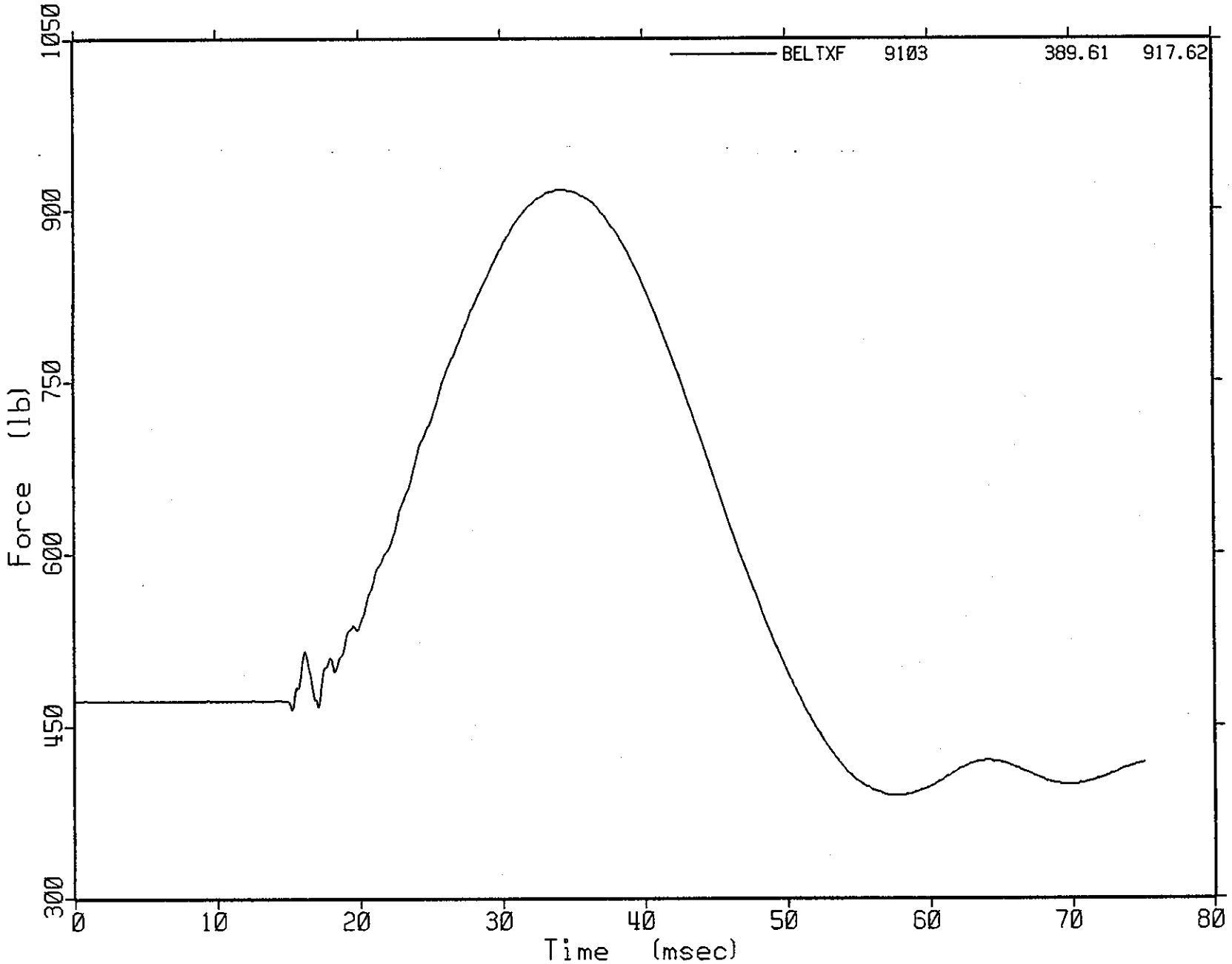


9103

8-OCT-92 17:41



TEST 9103 - FORCE

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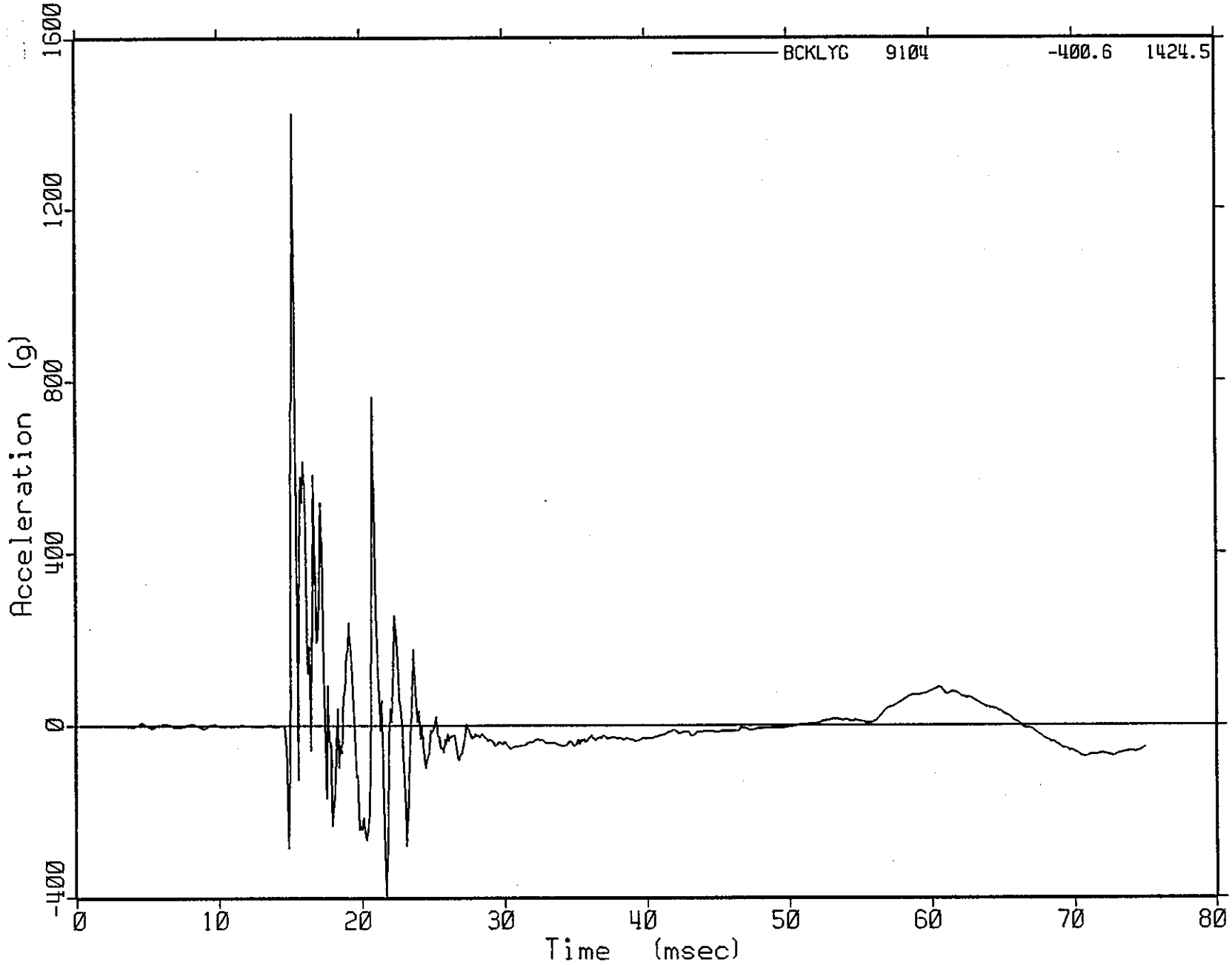
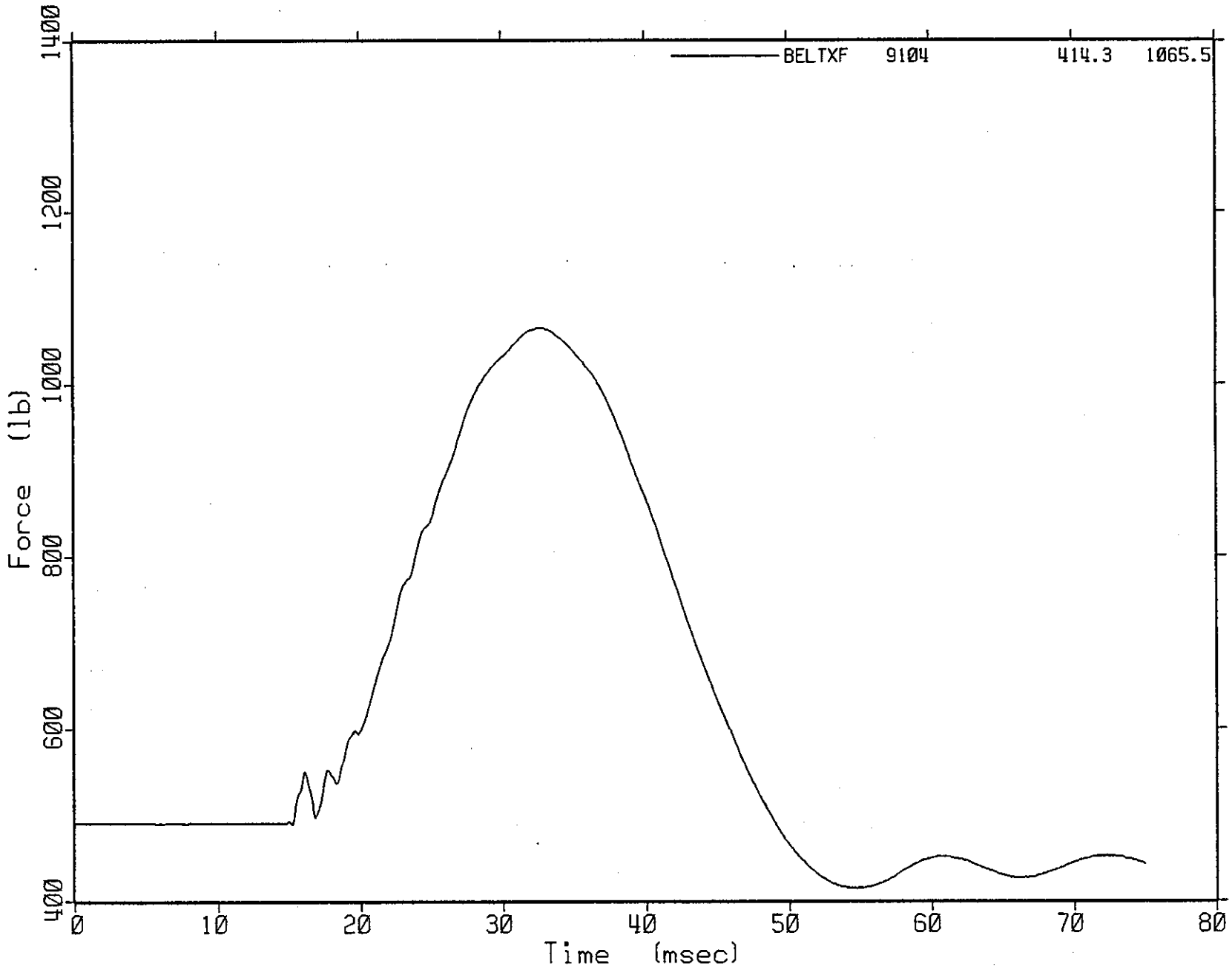


TEST 9104 - ACCELERATION

8-OCT-92 17:41



TEST 9104 - FORCE

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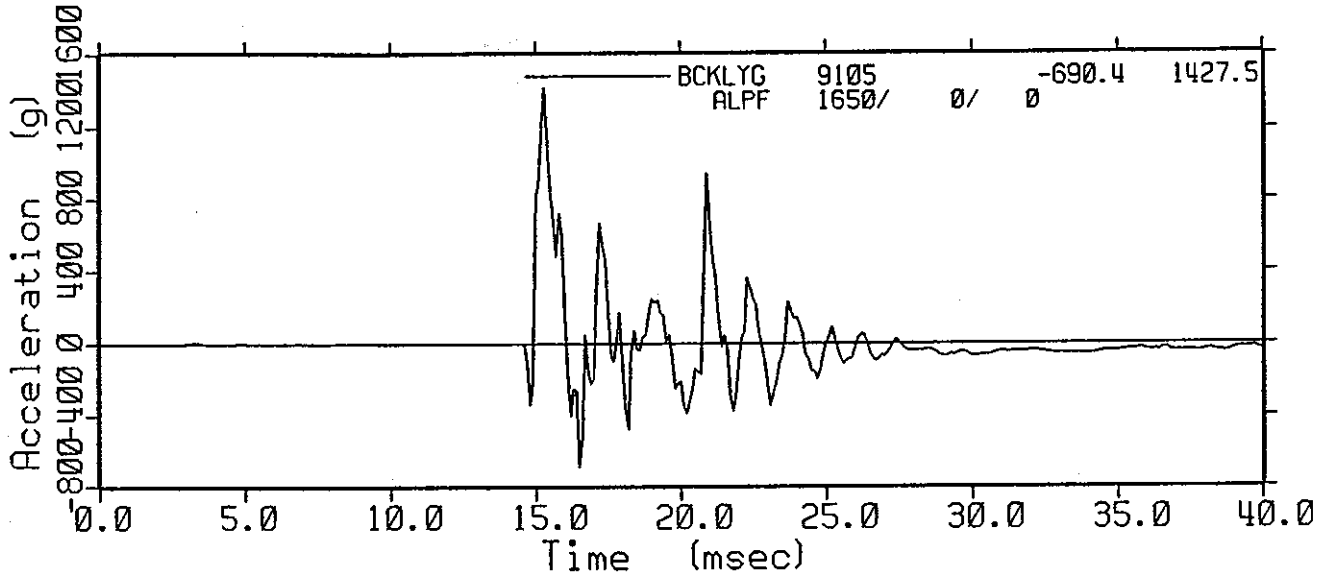

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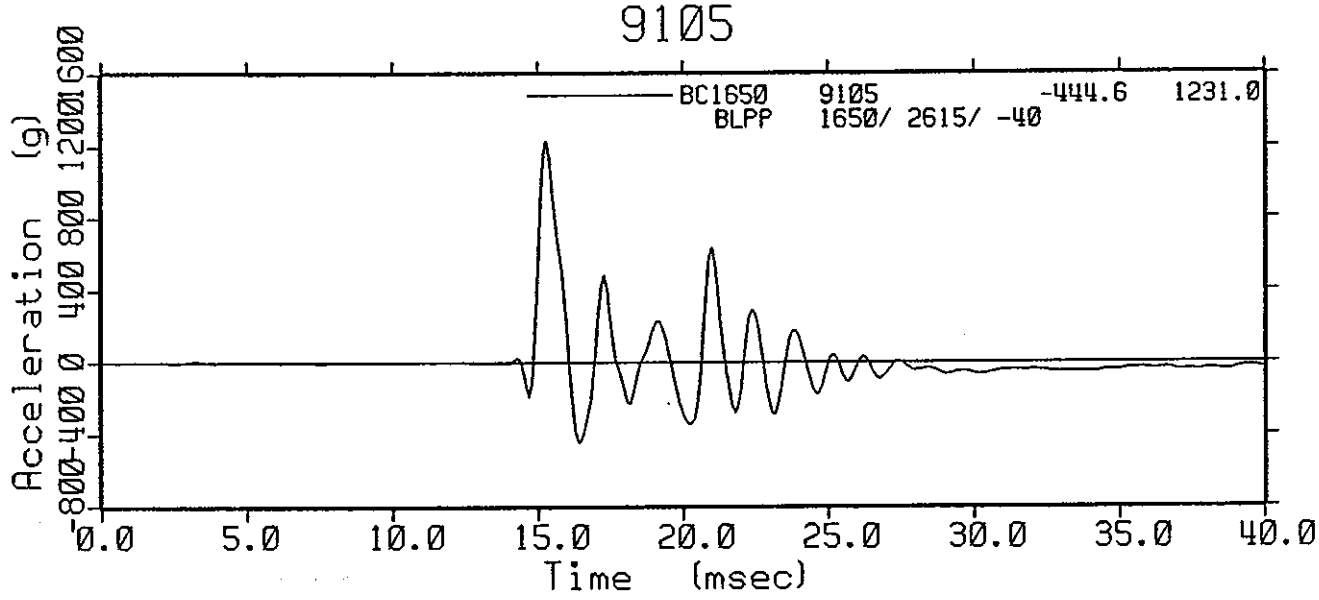

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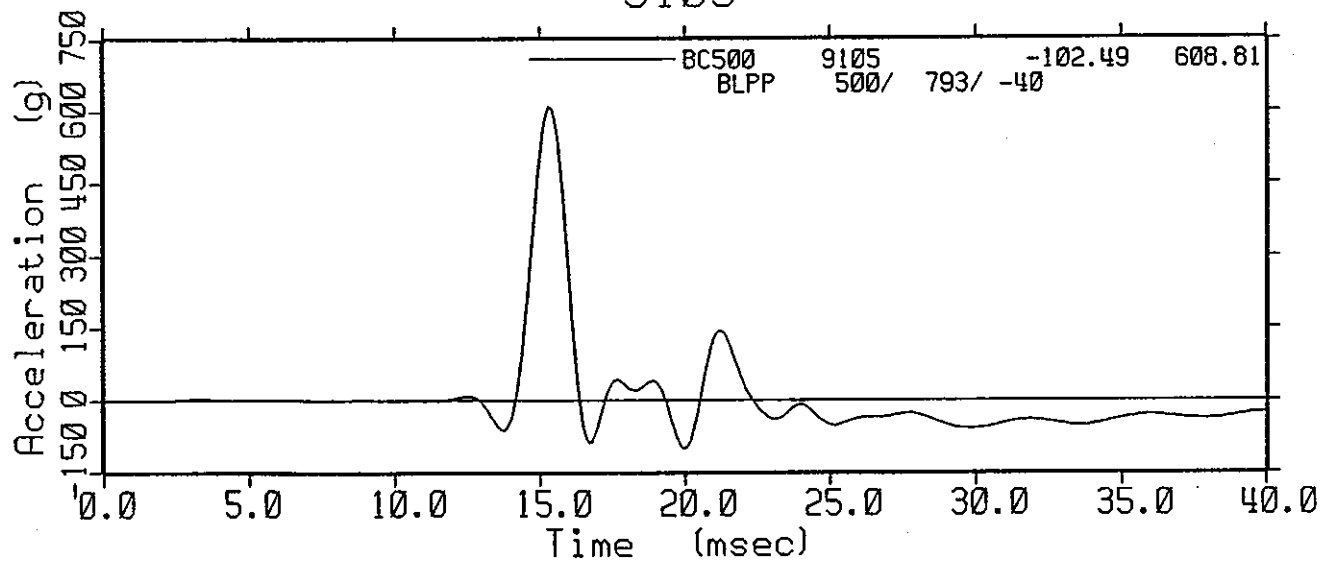

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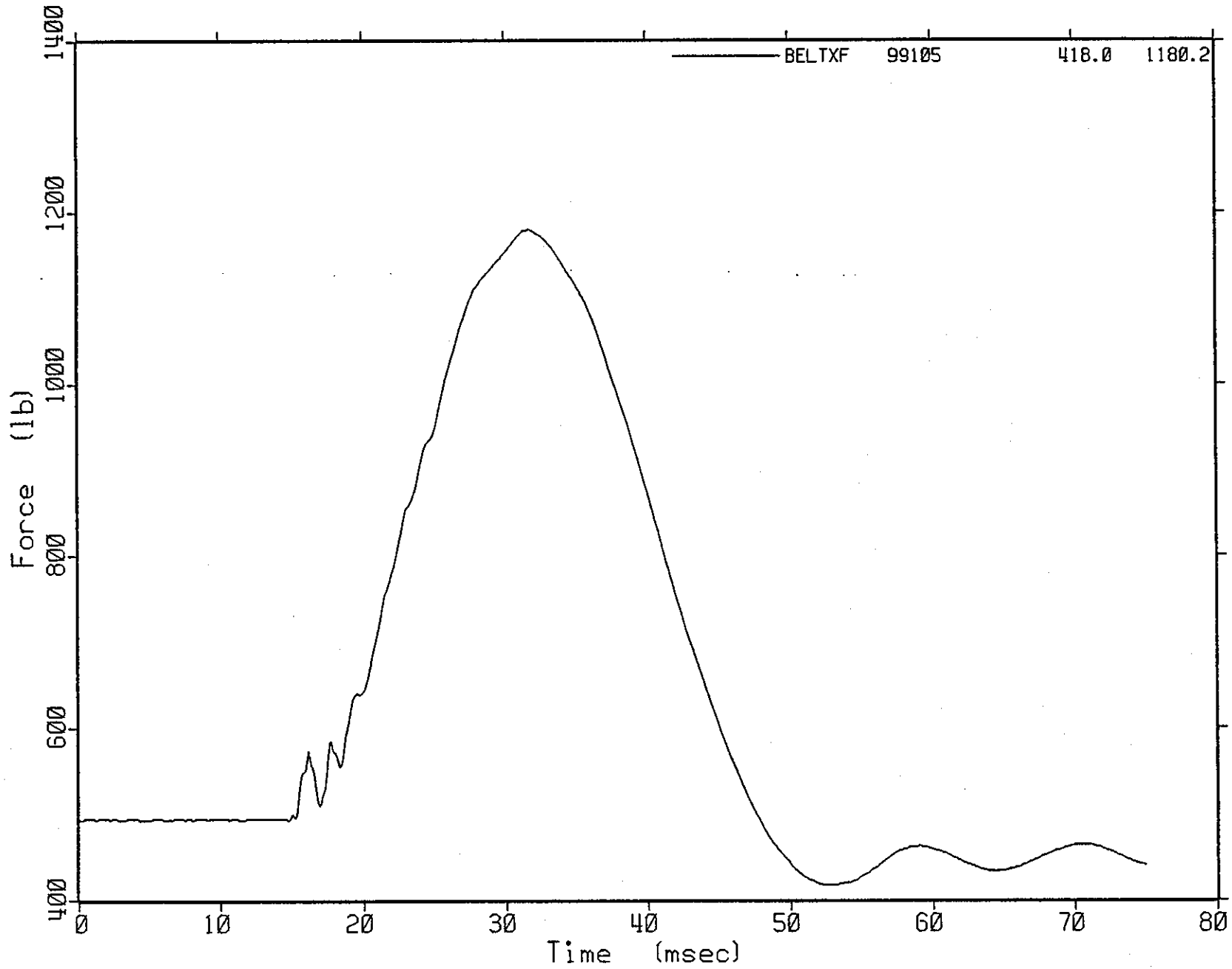

TEST 9105 - FORCE

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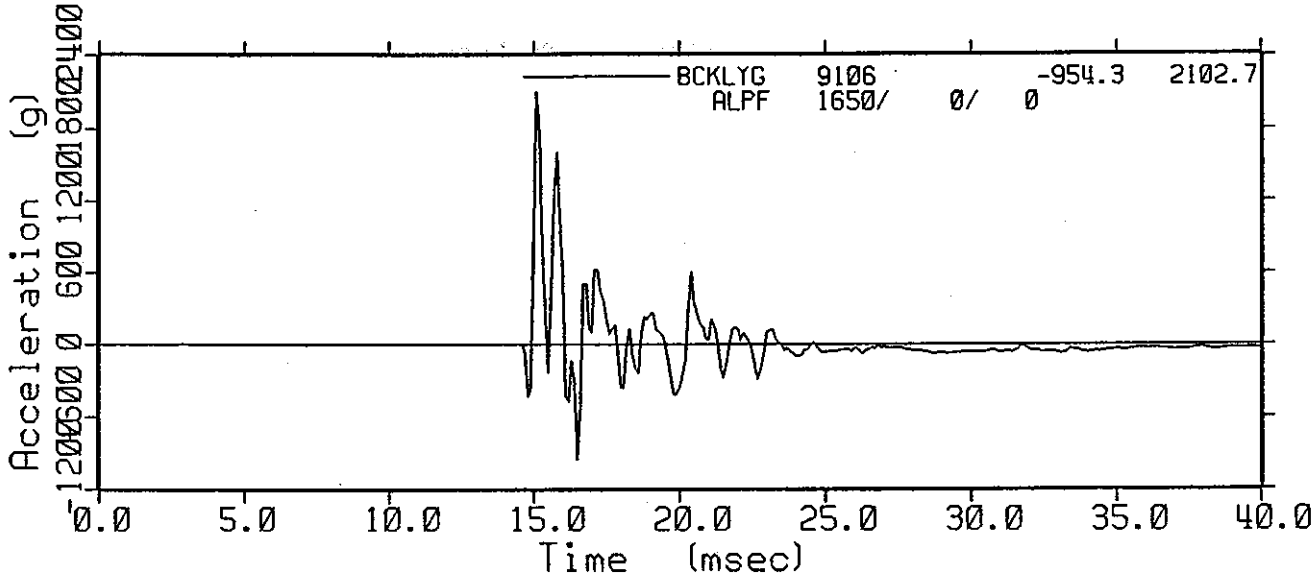

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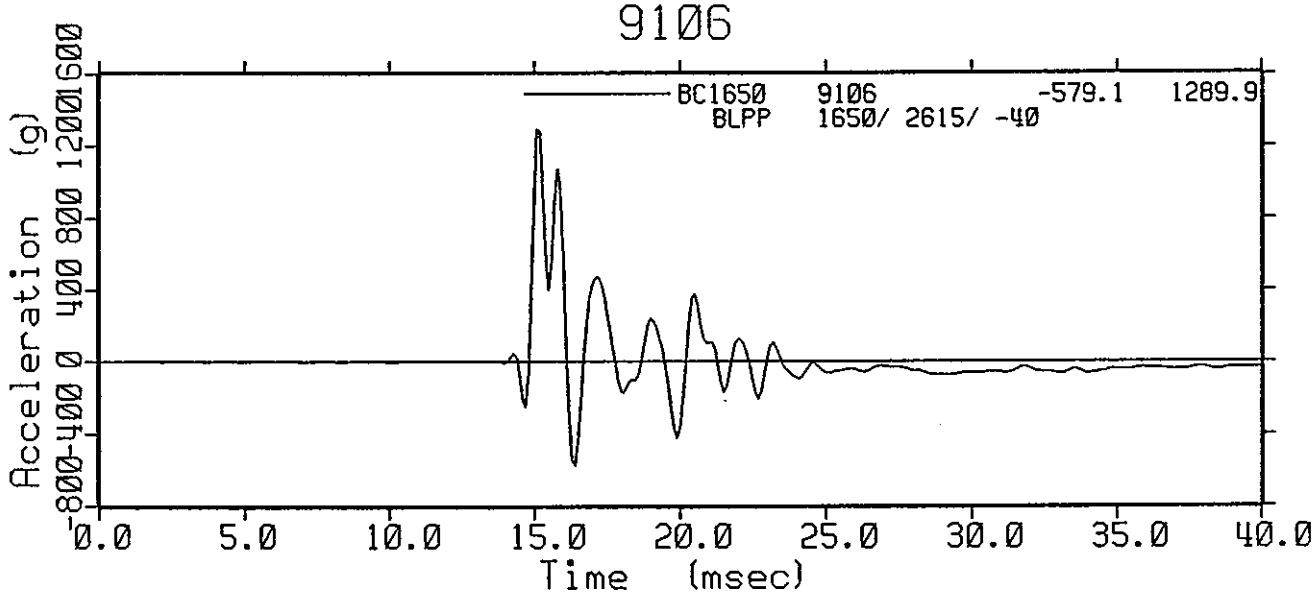

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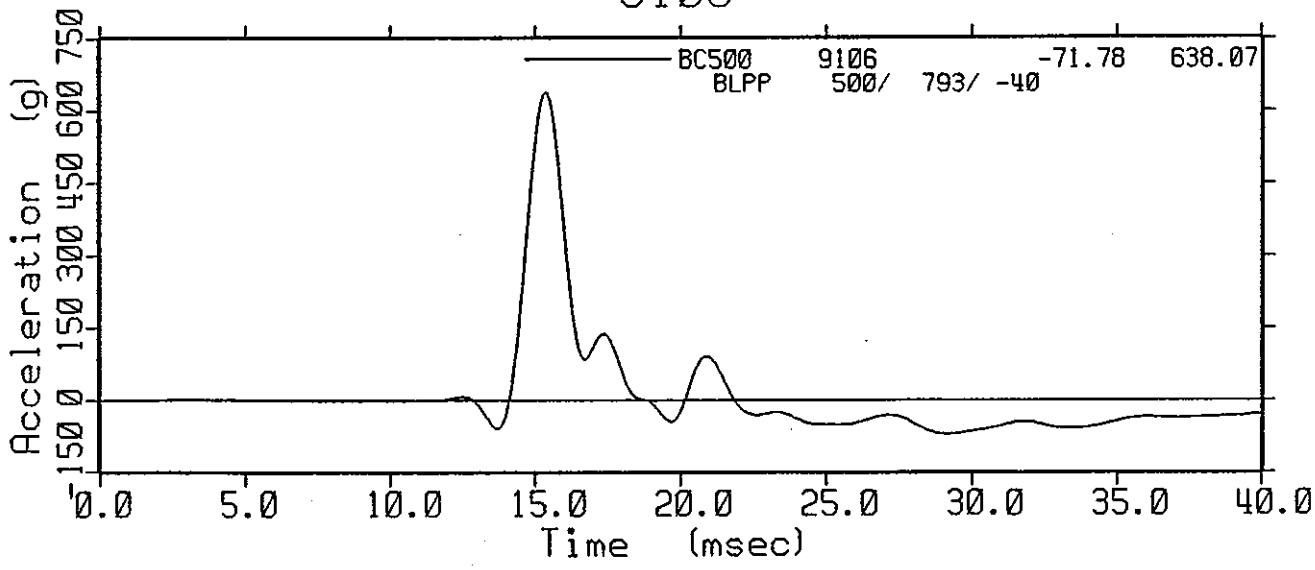

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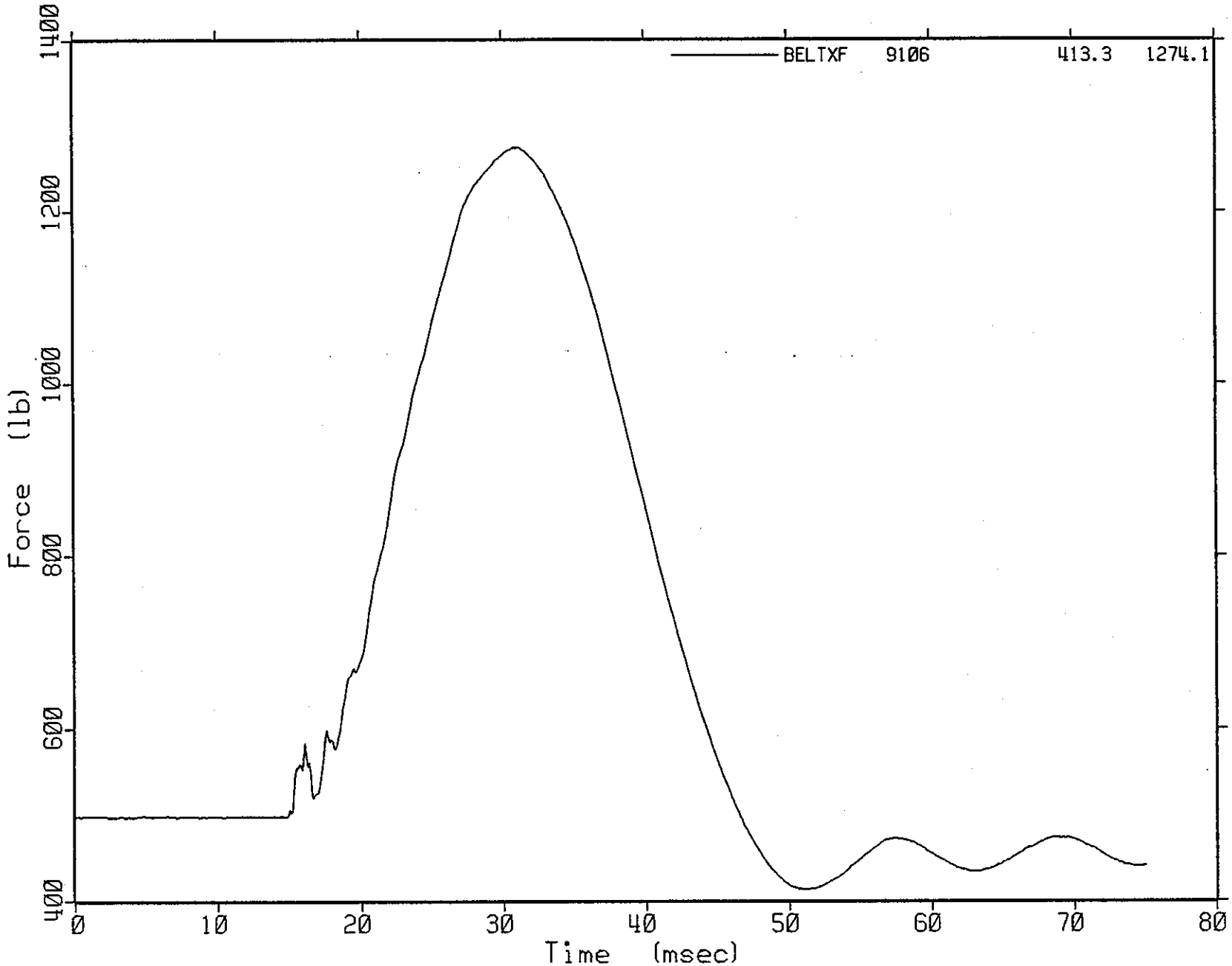
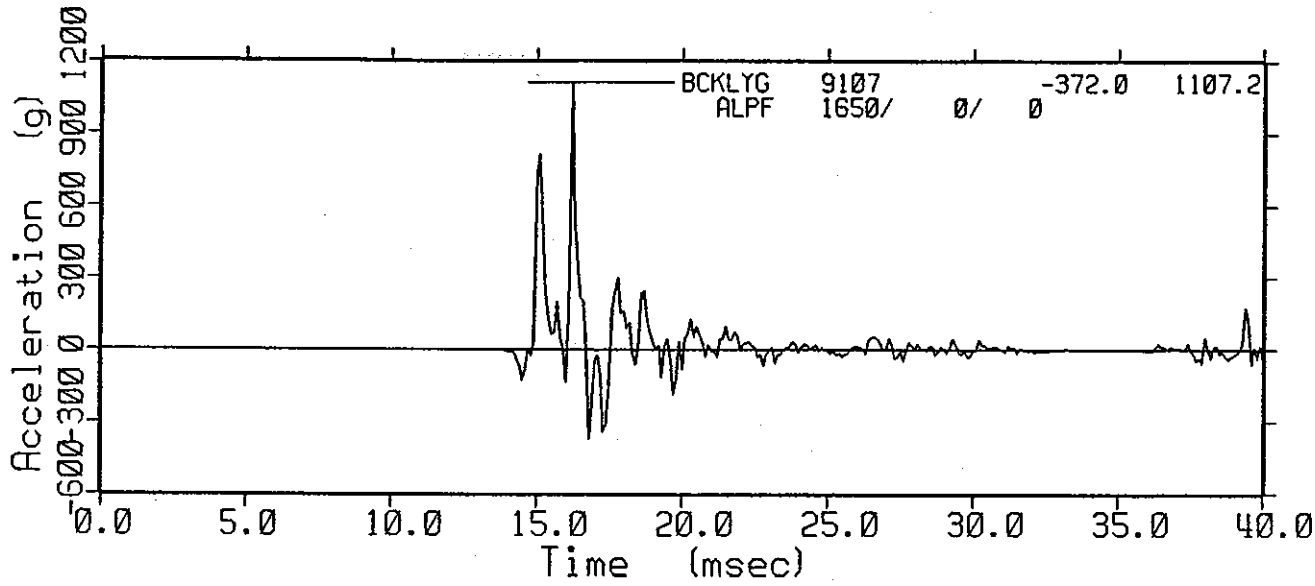


TEST 9106 - FORCE

8-OCT-92 20:25



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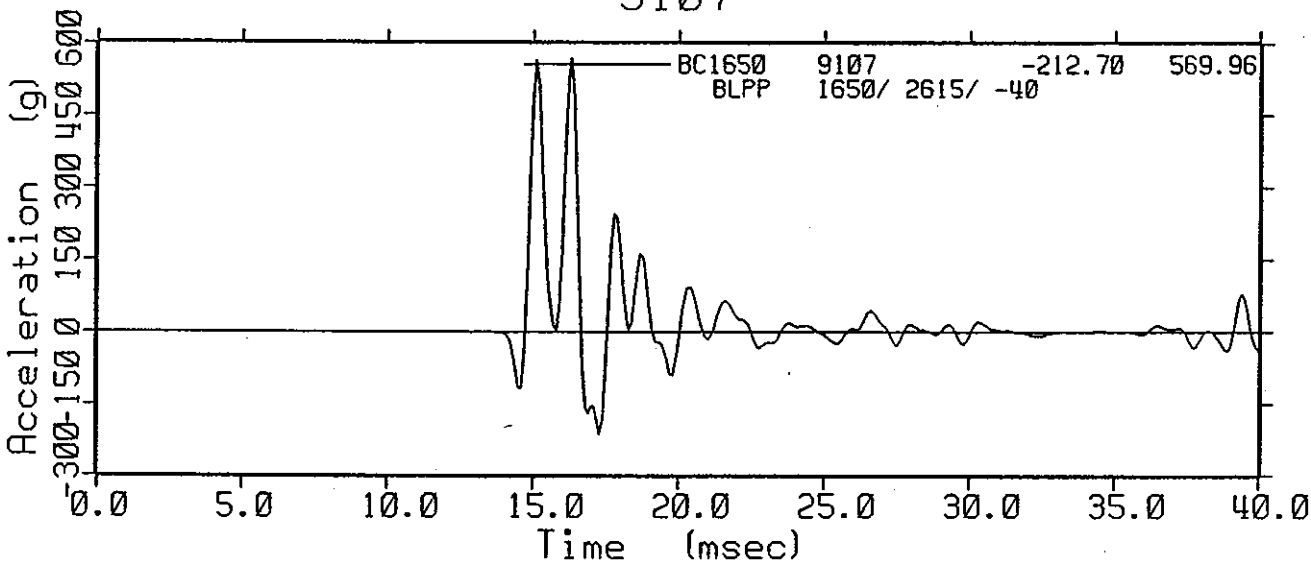

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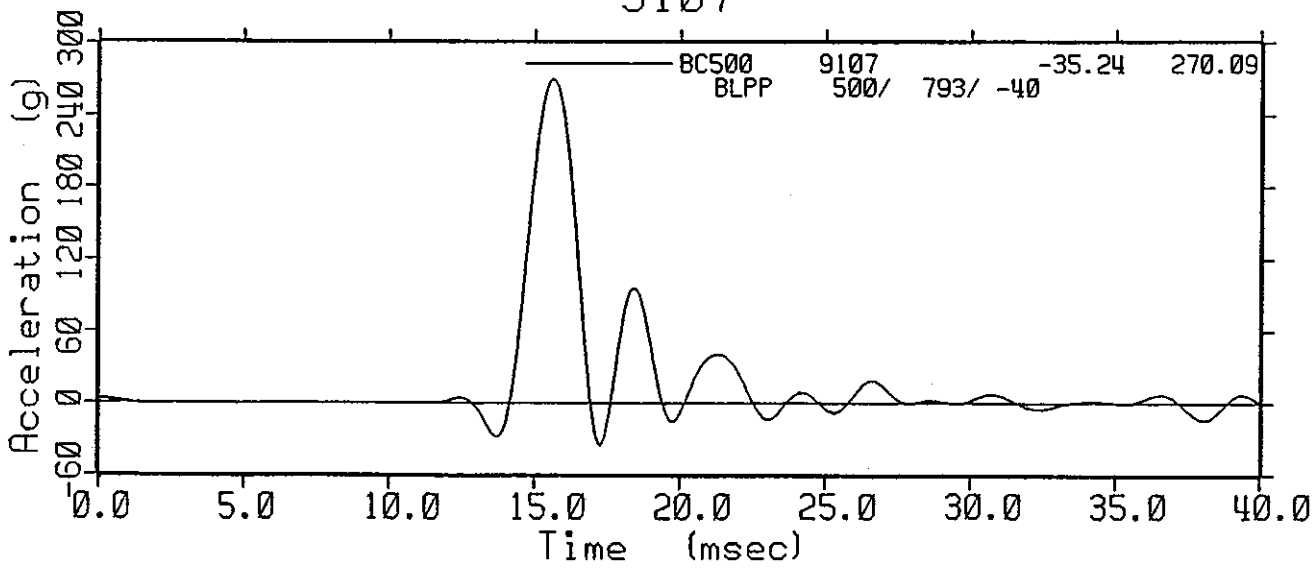

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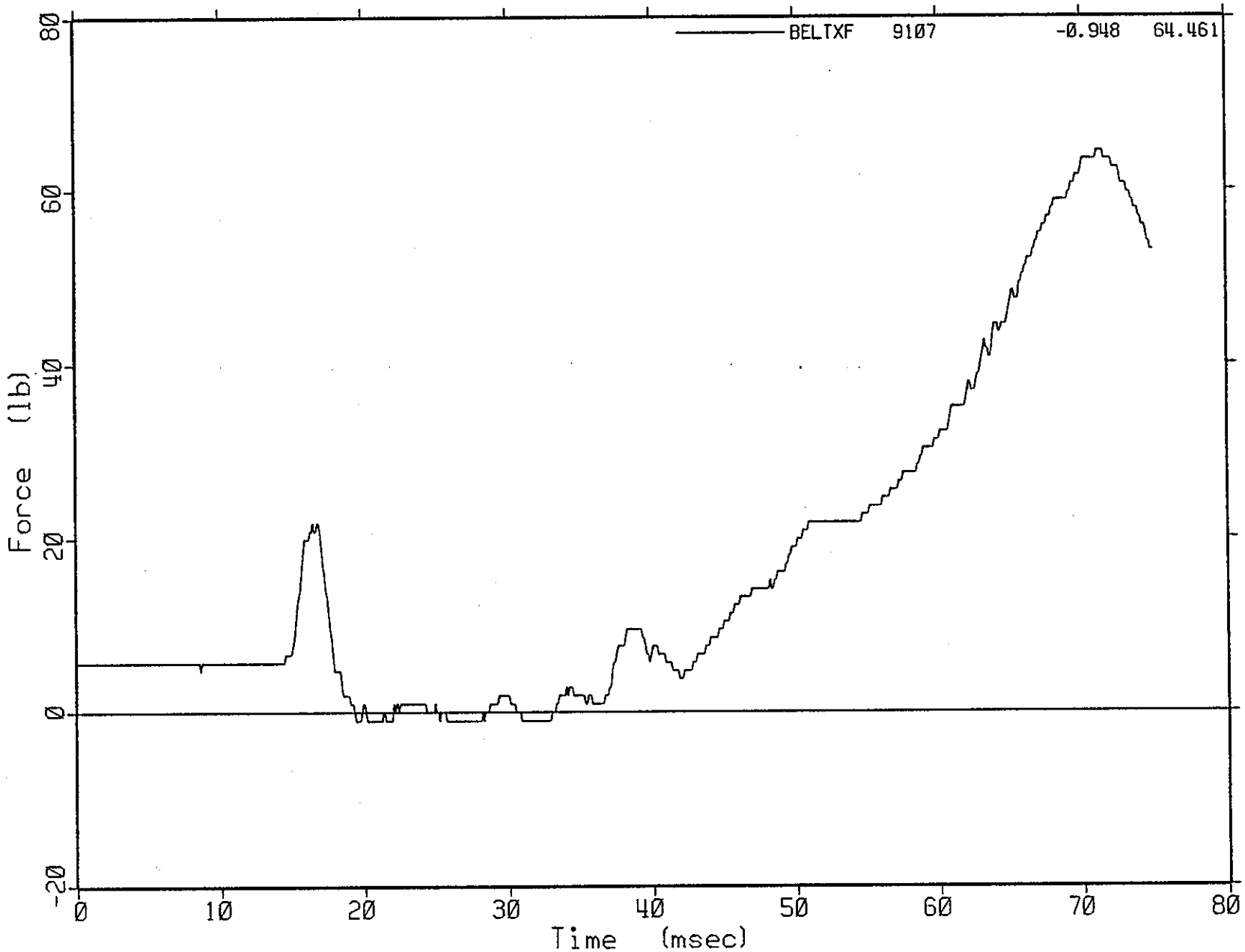

TEST 9107 - FORCE

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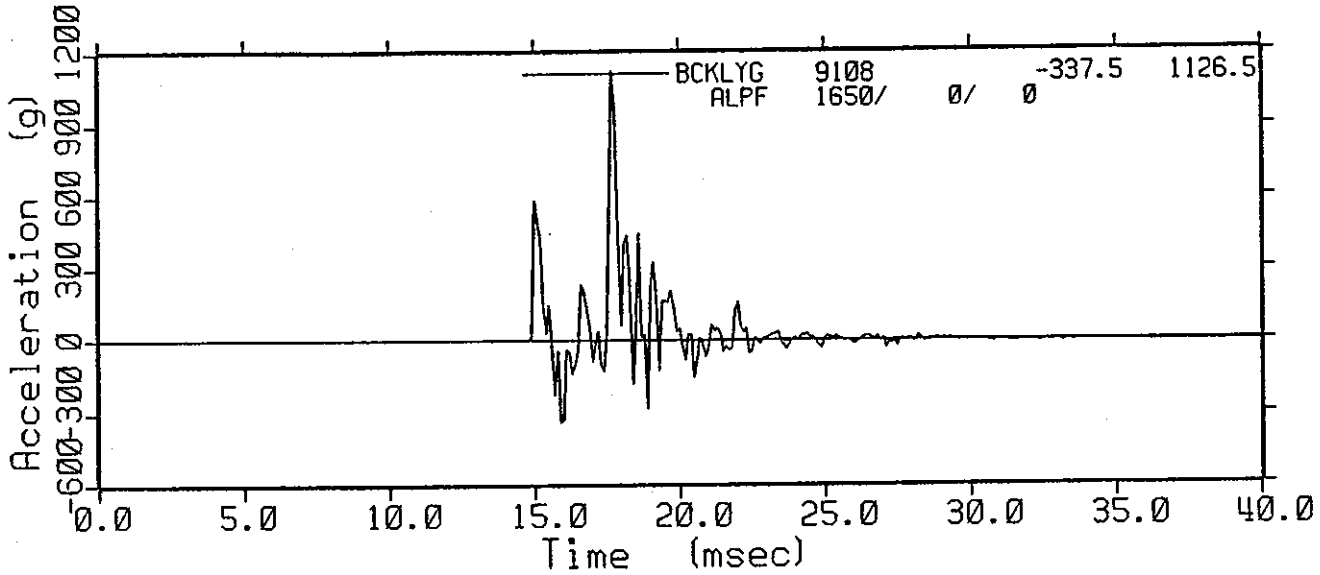

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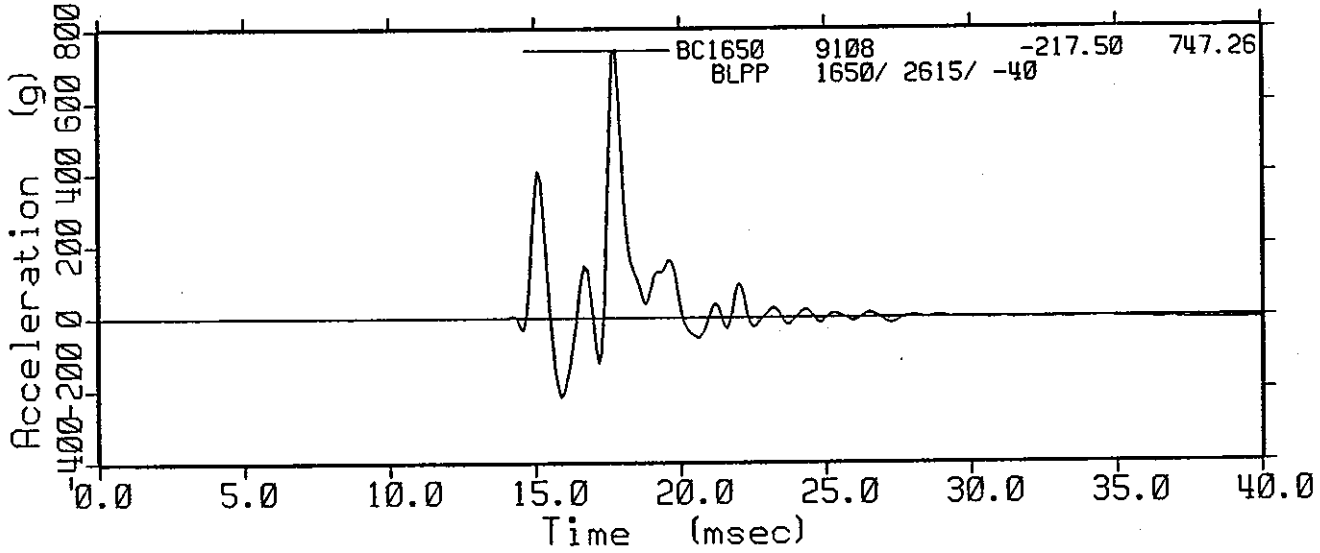

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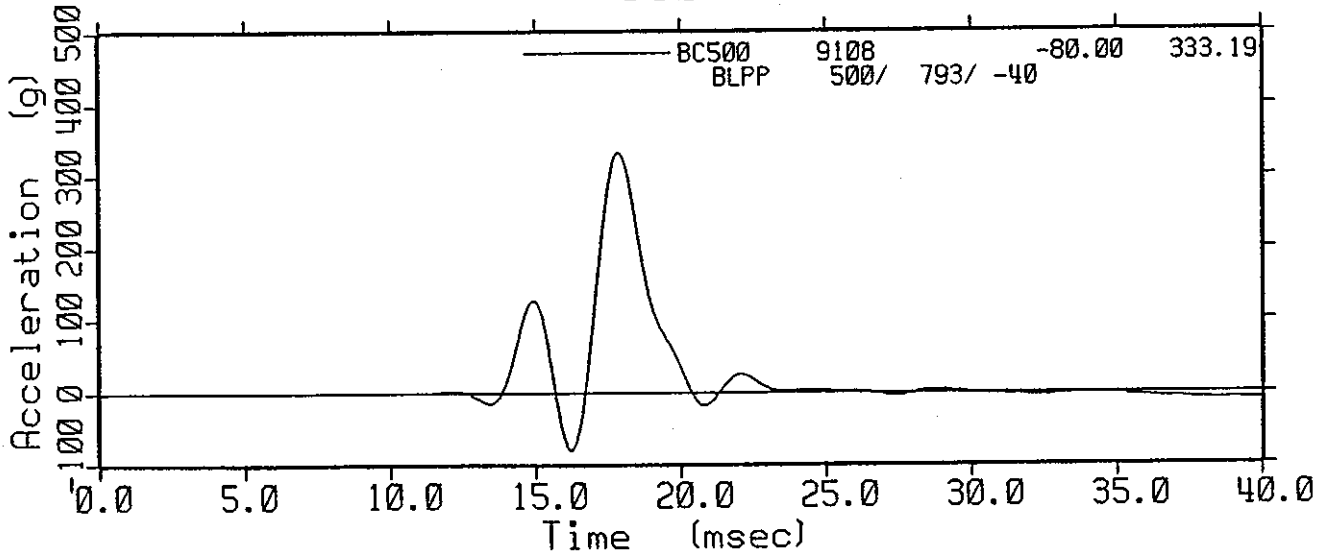

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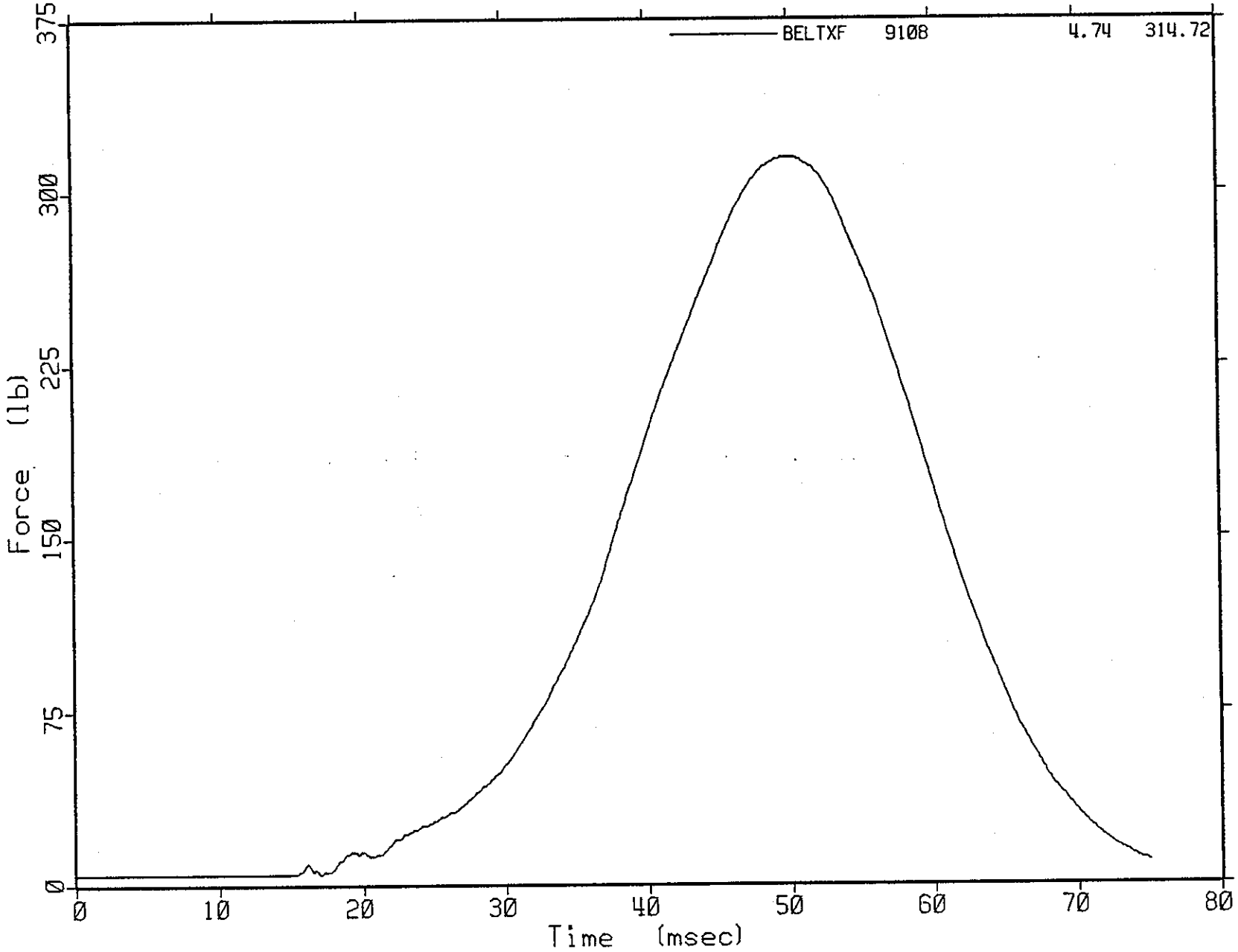

TEST 9108 - FORCE

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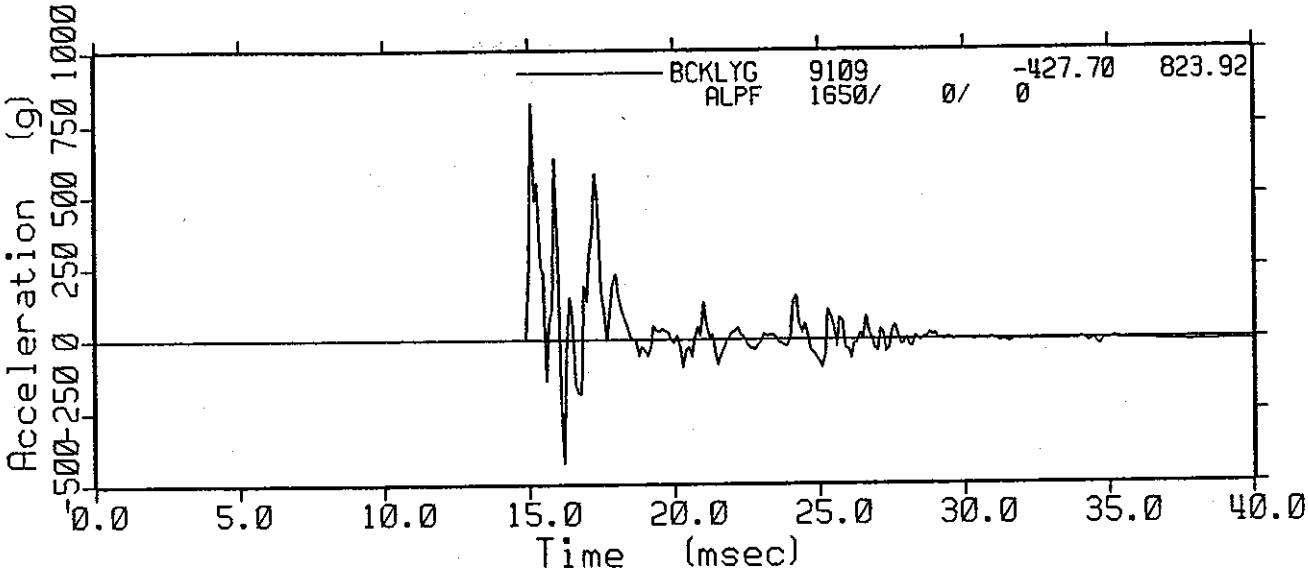

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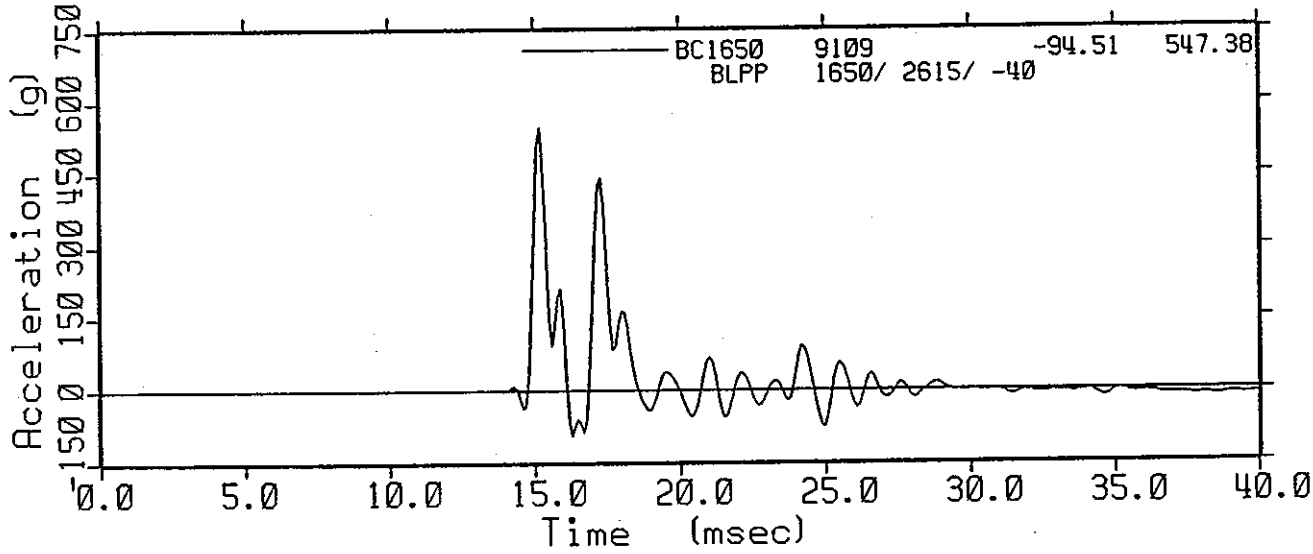

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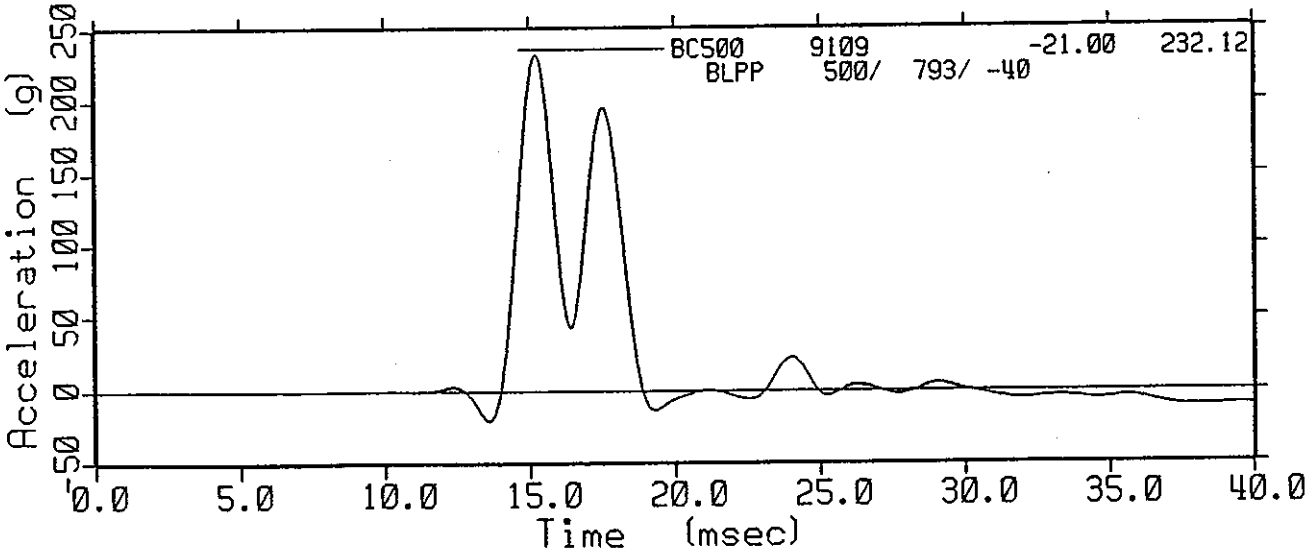

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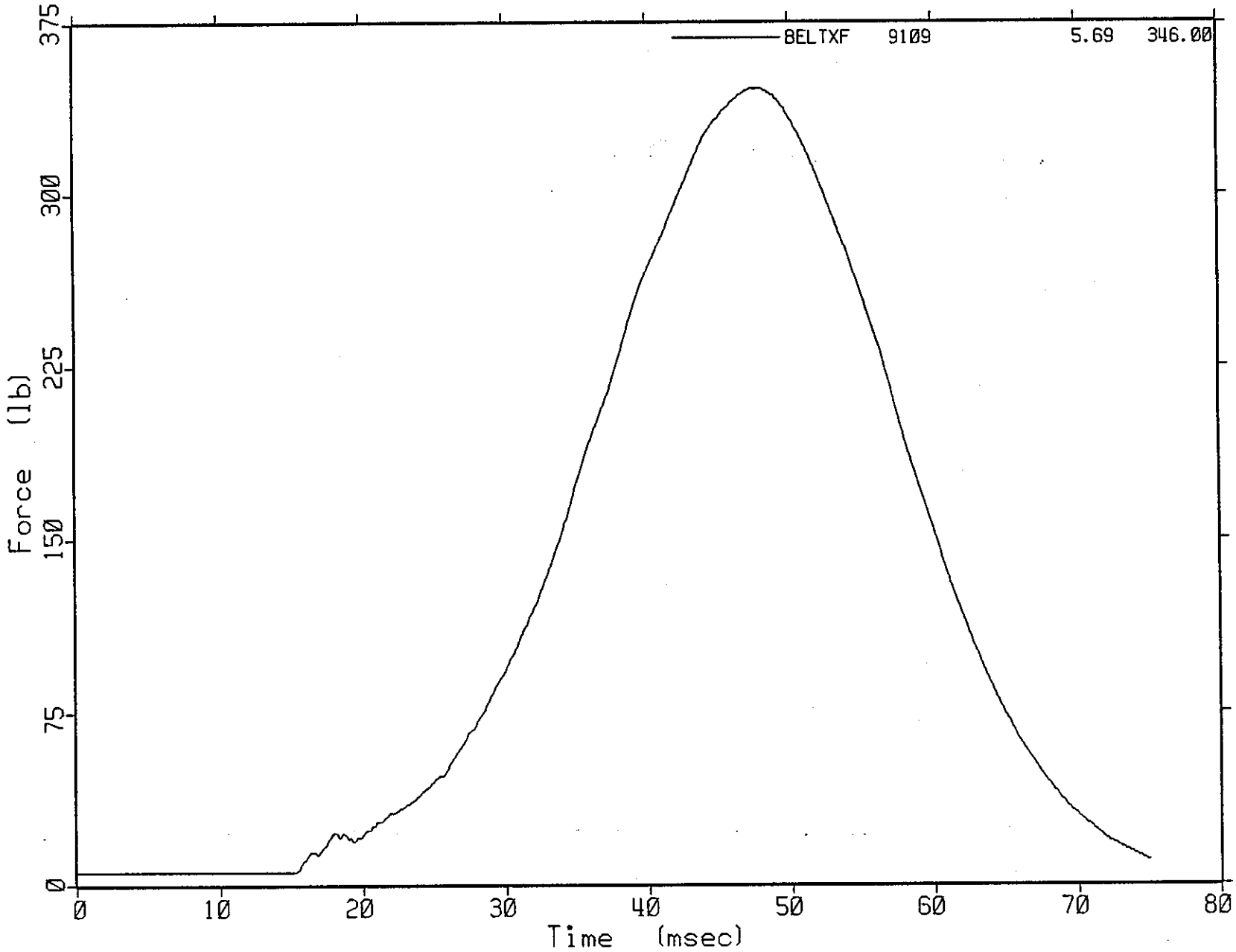
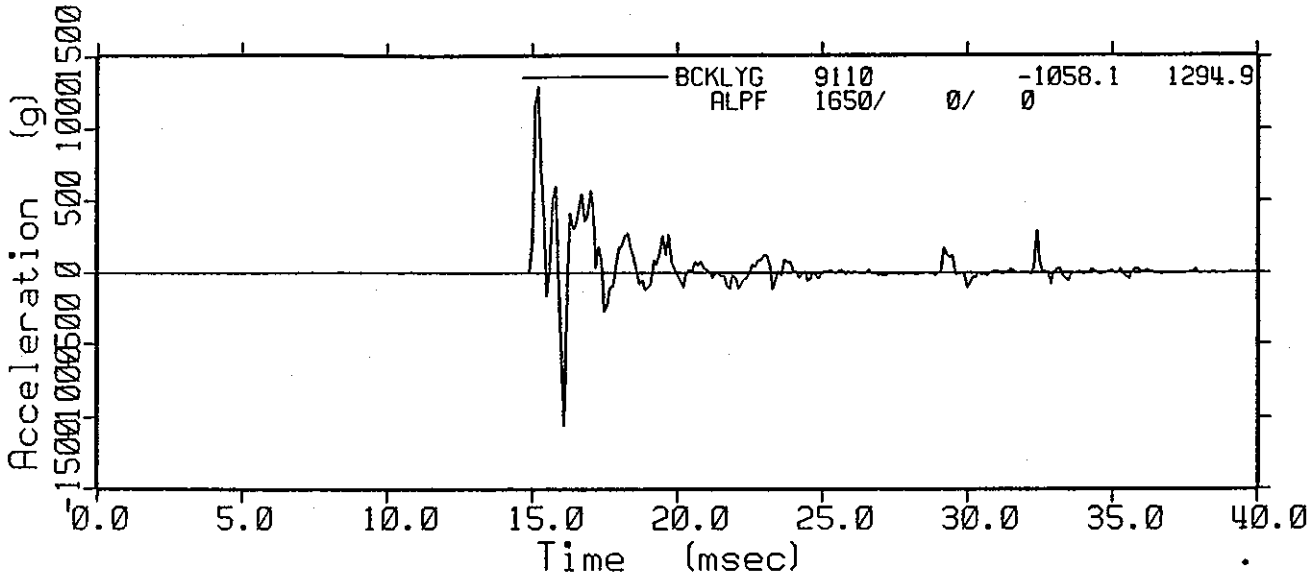


TEST 9109 - FORCE

8-OCT-92 20:25



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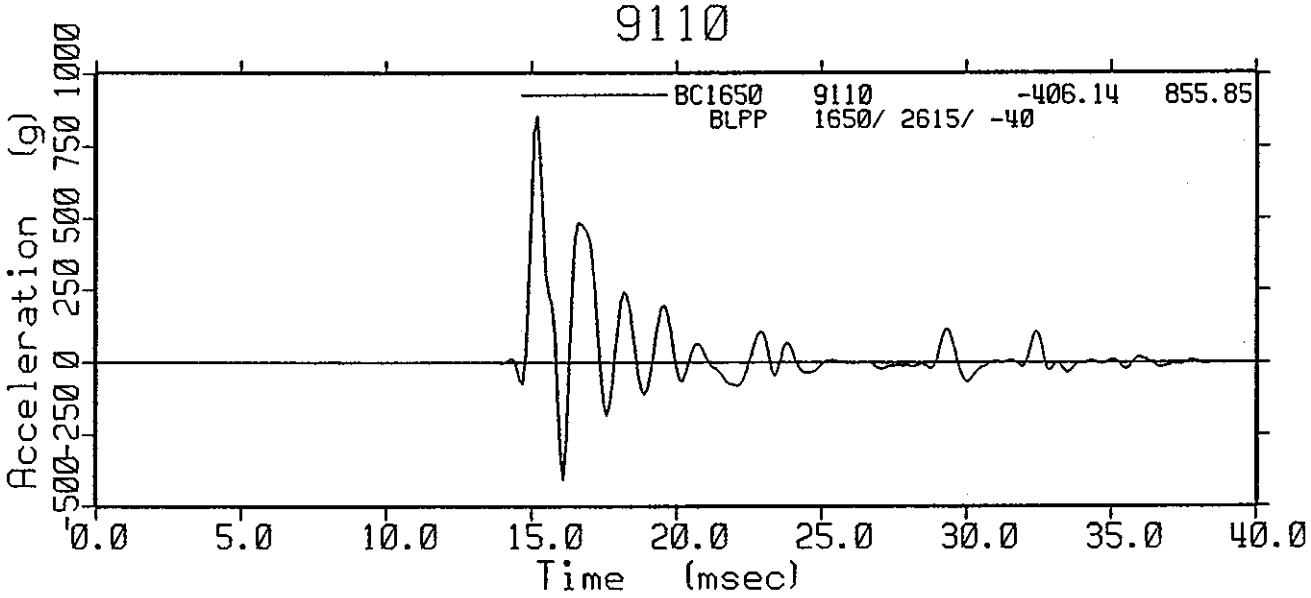

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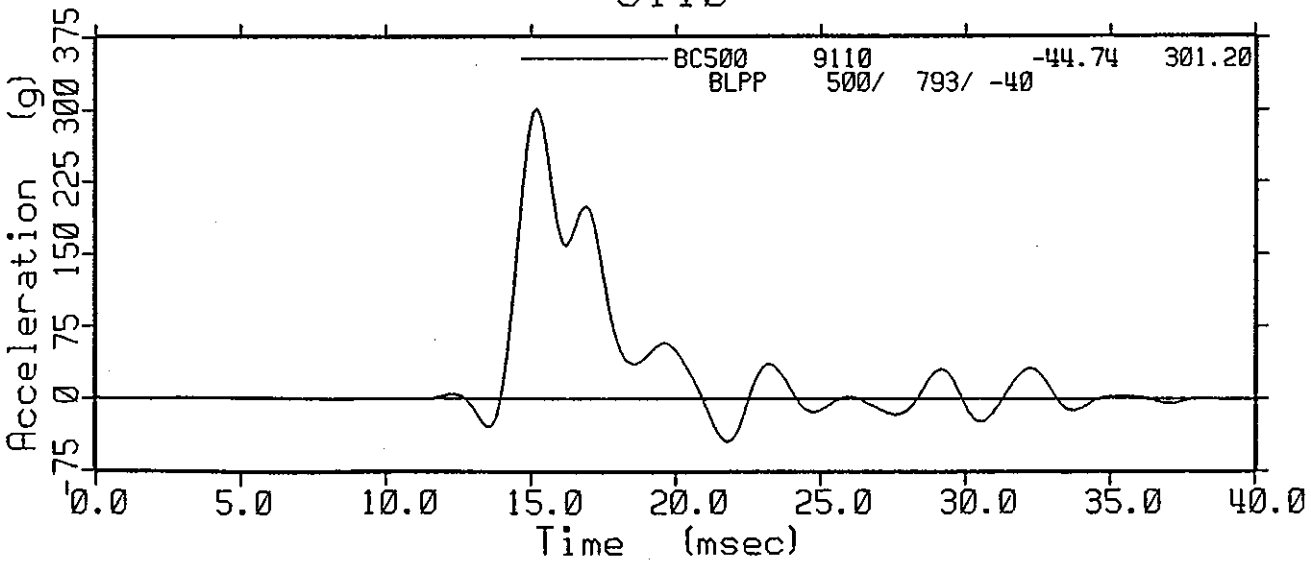

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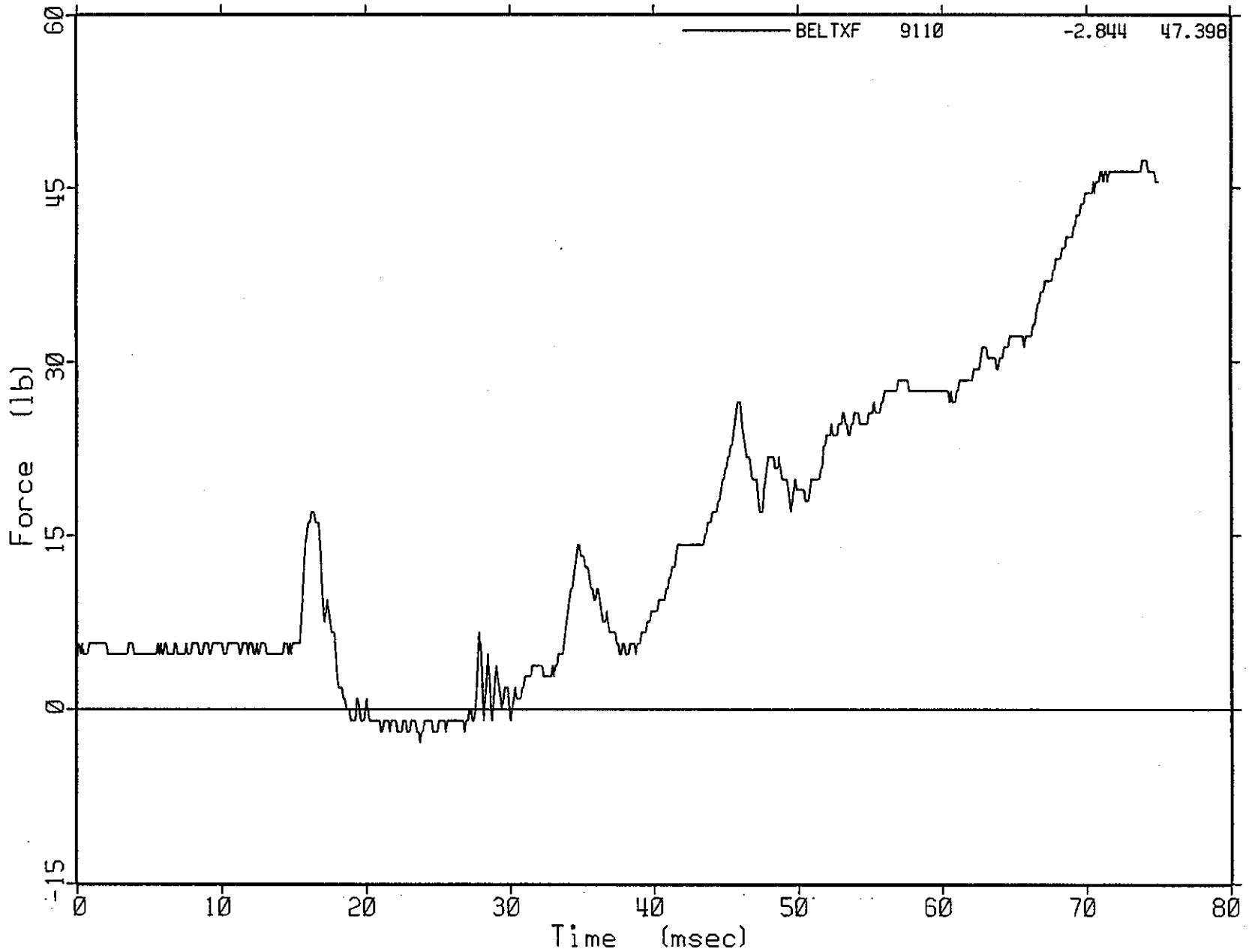

TEST 9110 - FORCE

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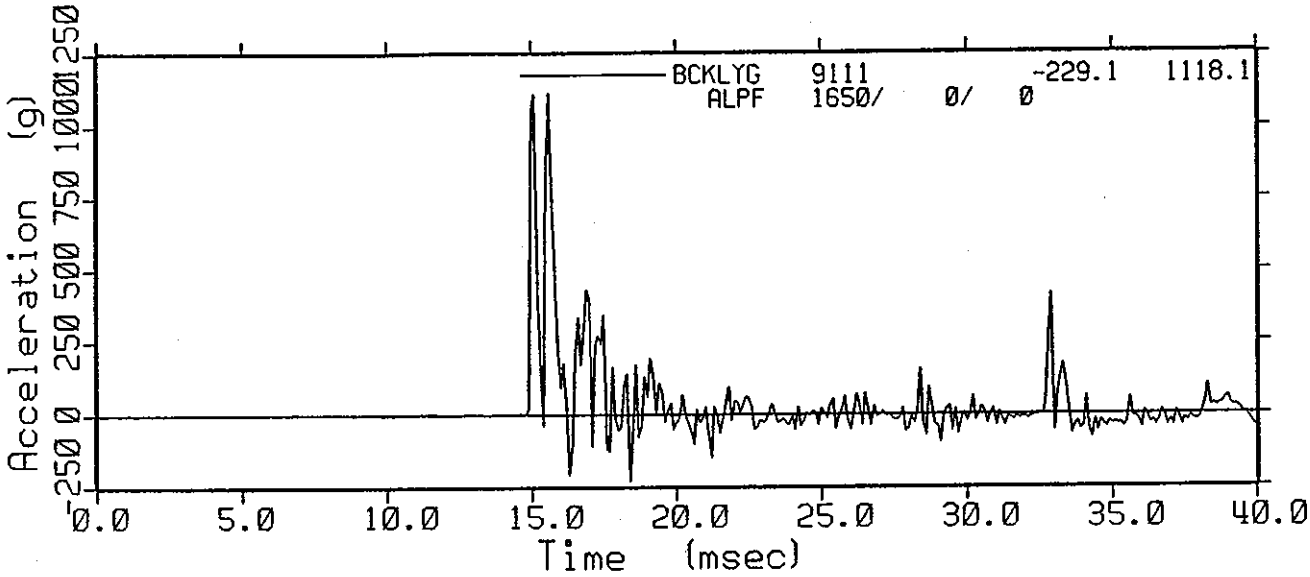

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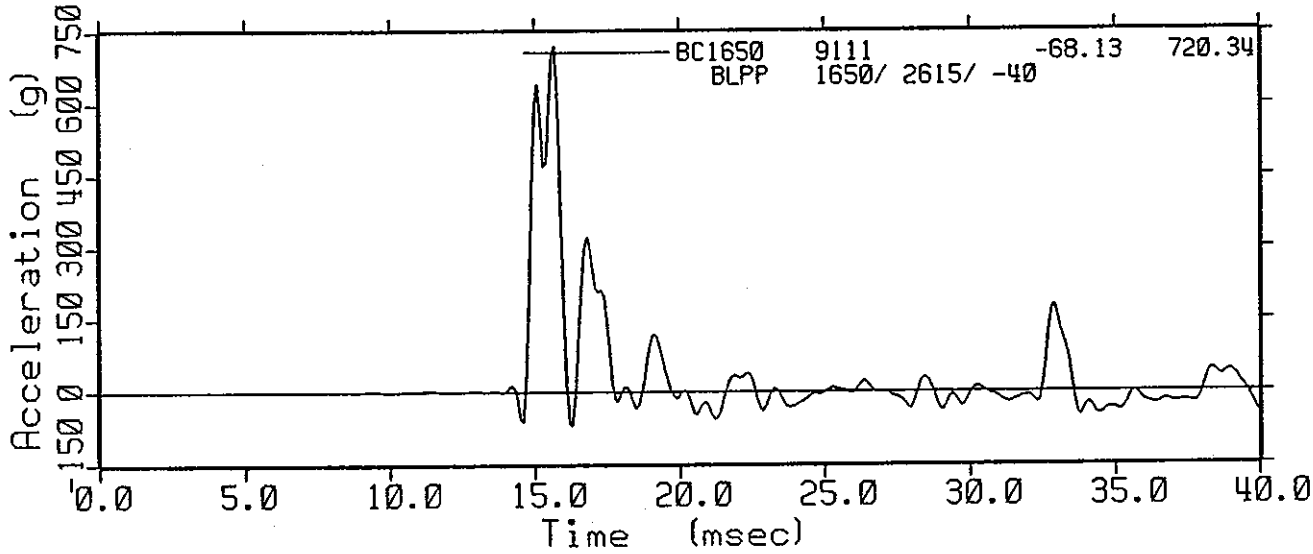

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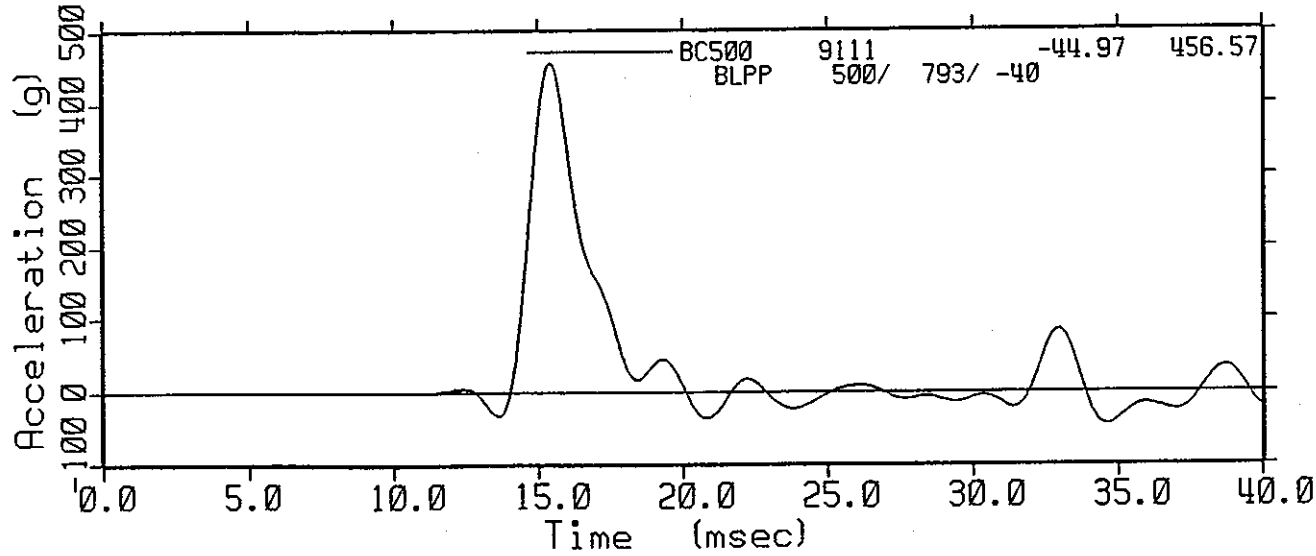

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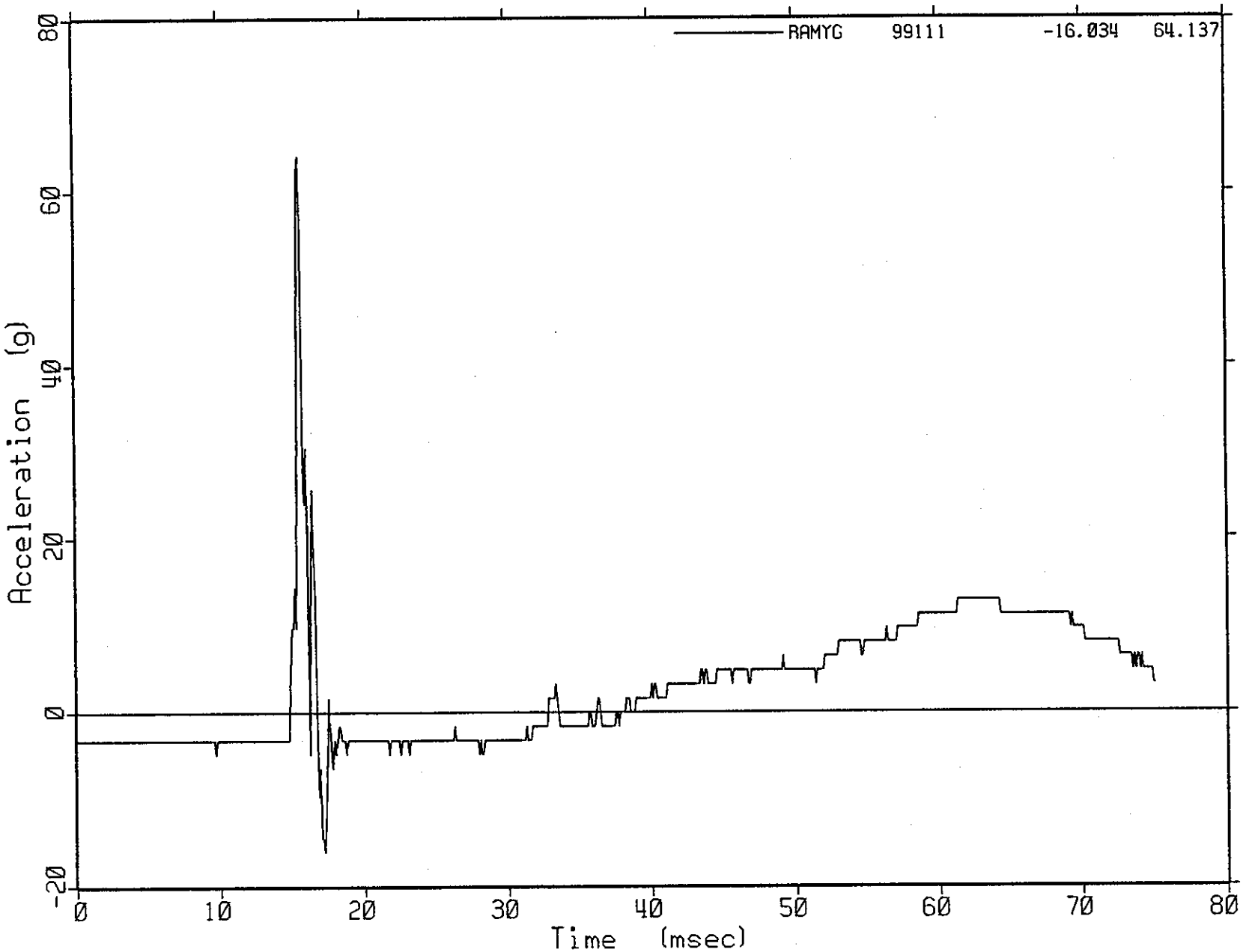
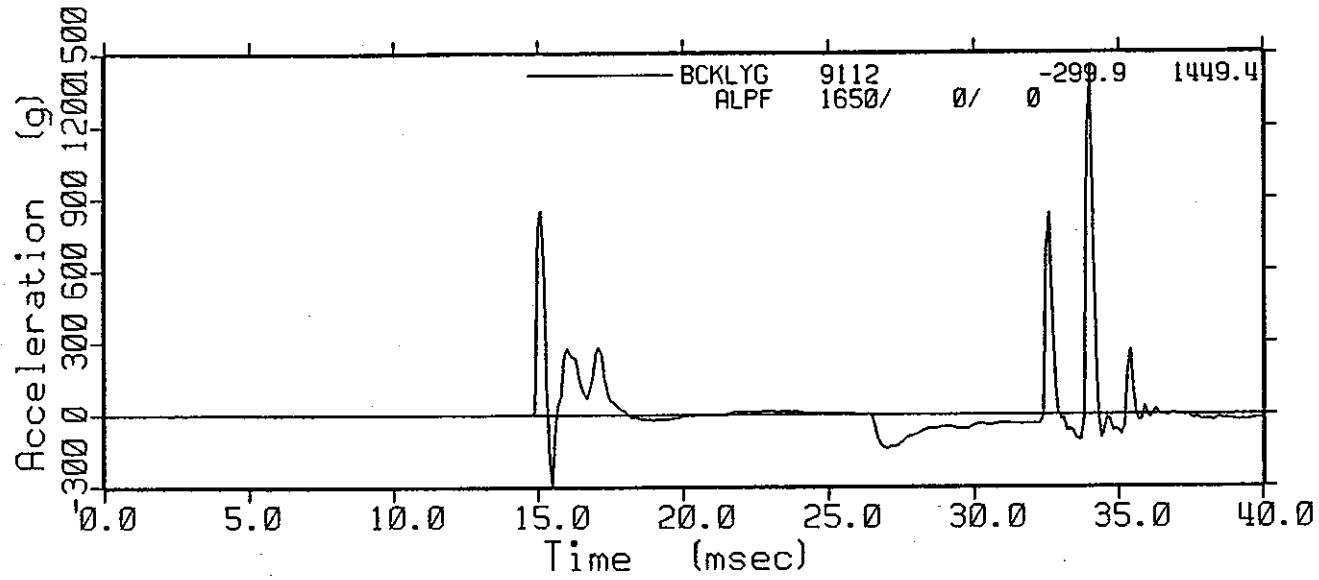


TEST 9111 - ACCELERATION

8-OCT-92 20:25



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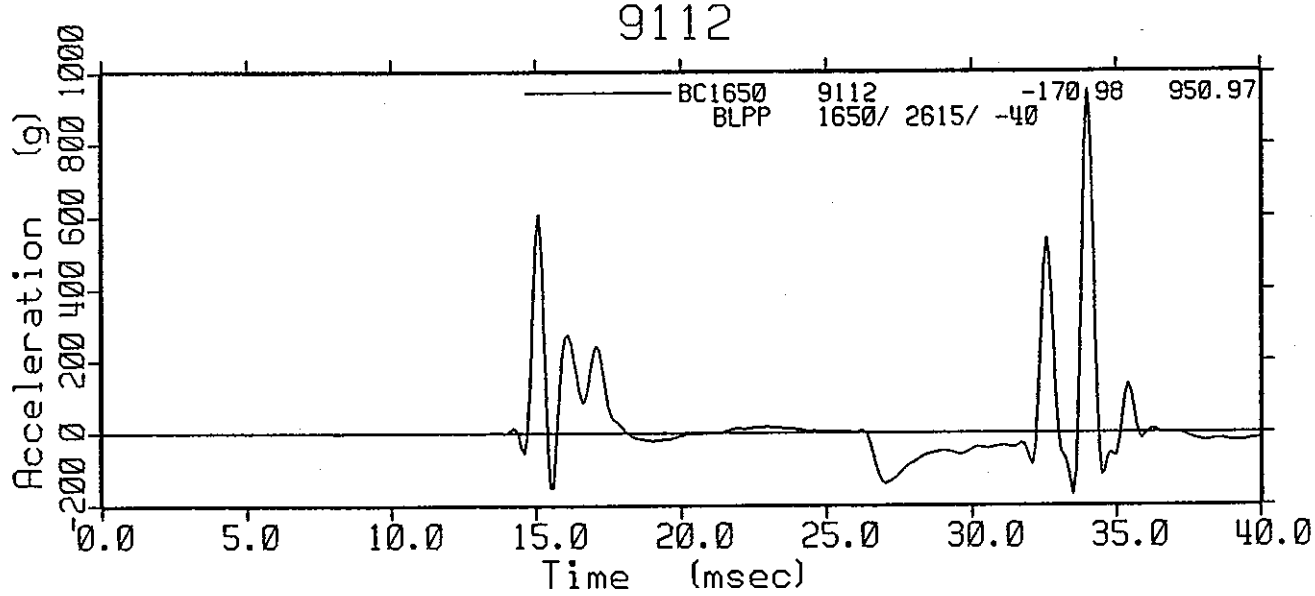

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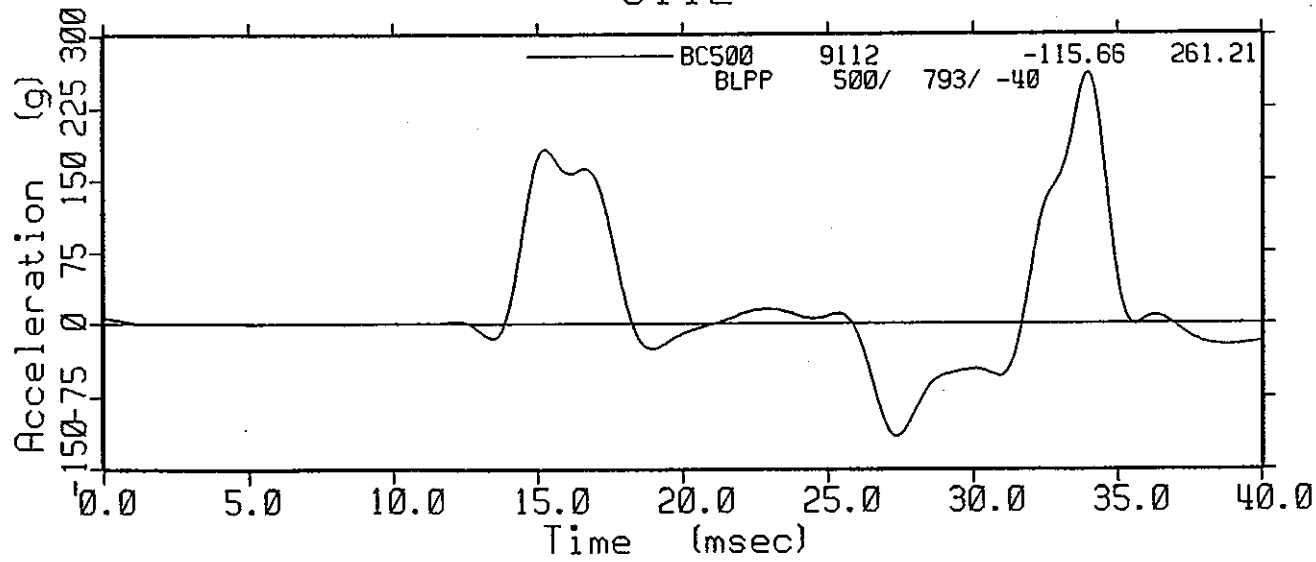
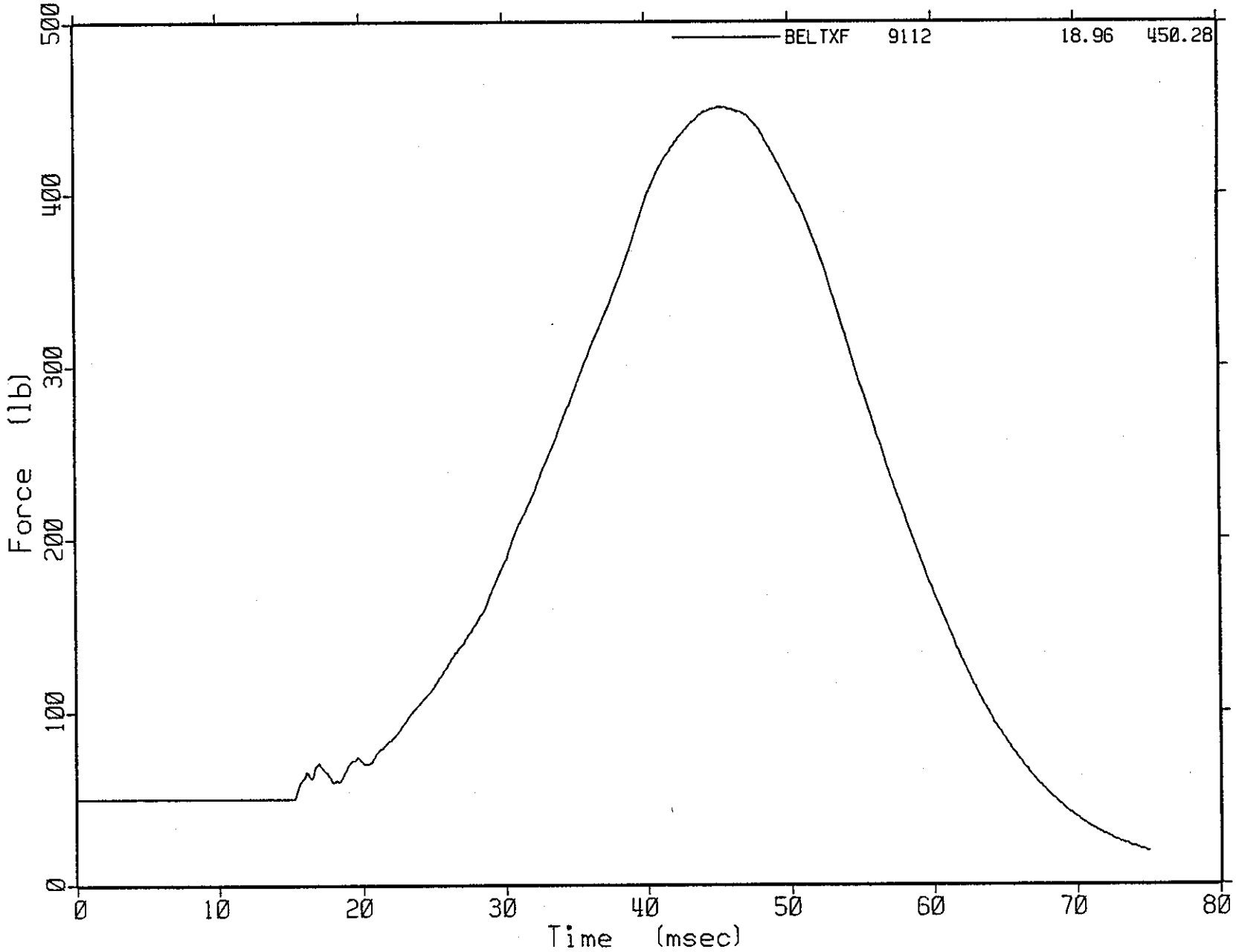


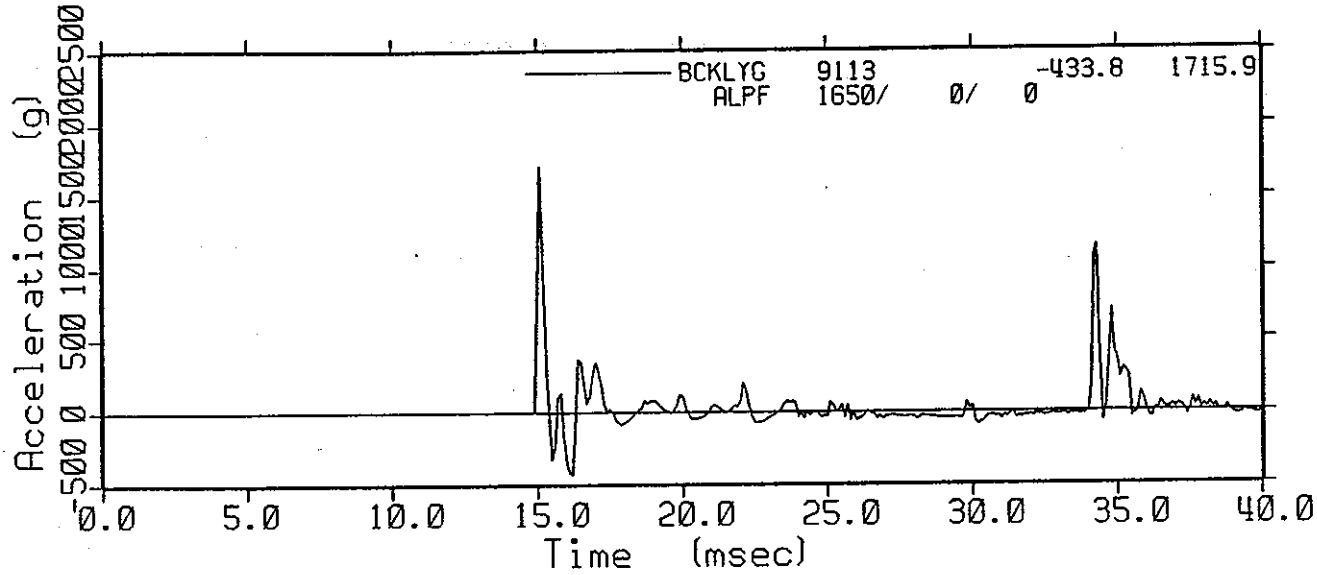
9112

8-OCT-92 17:53



TEST 9112 - FORCE

8-OCT-92 20:25



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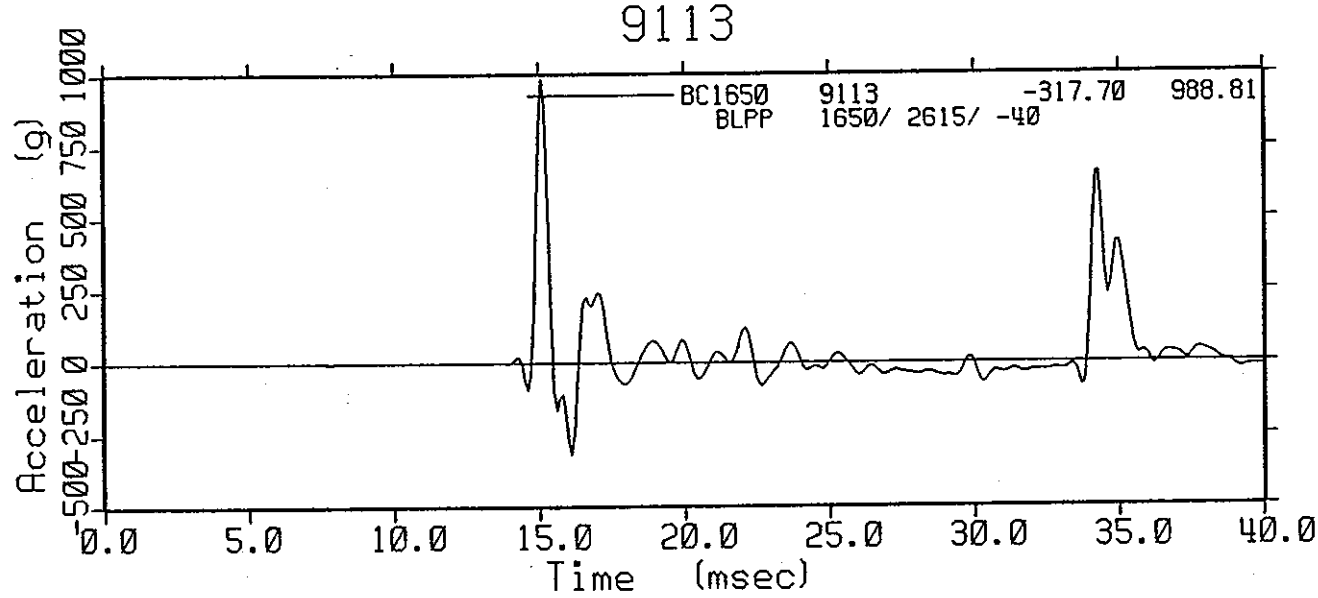

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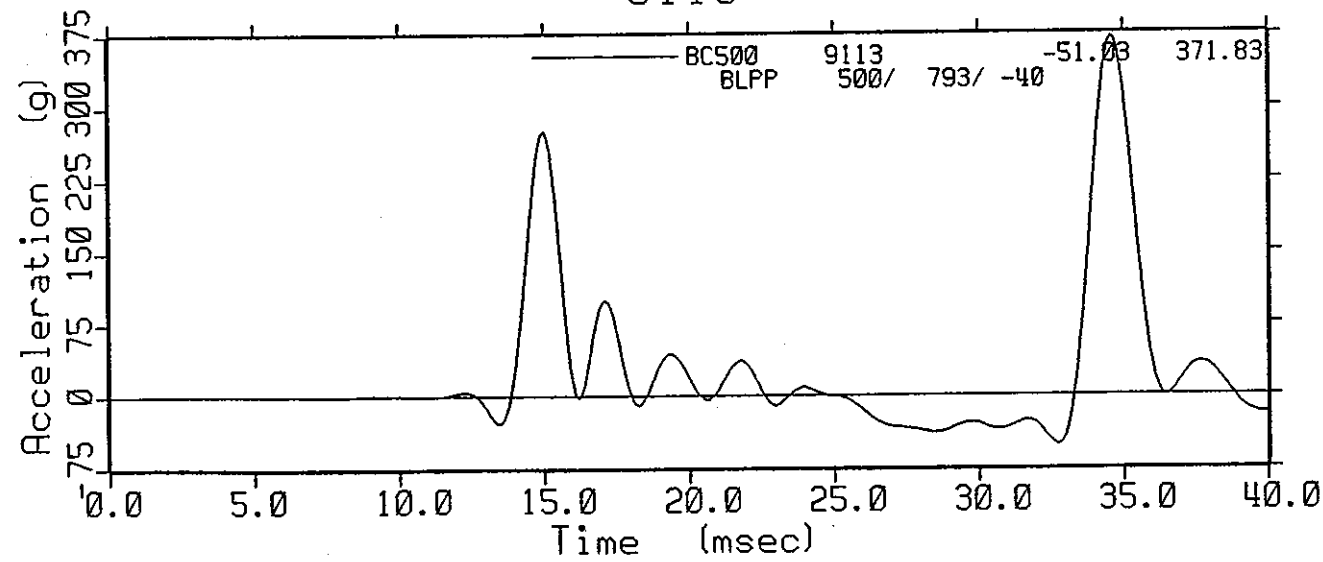

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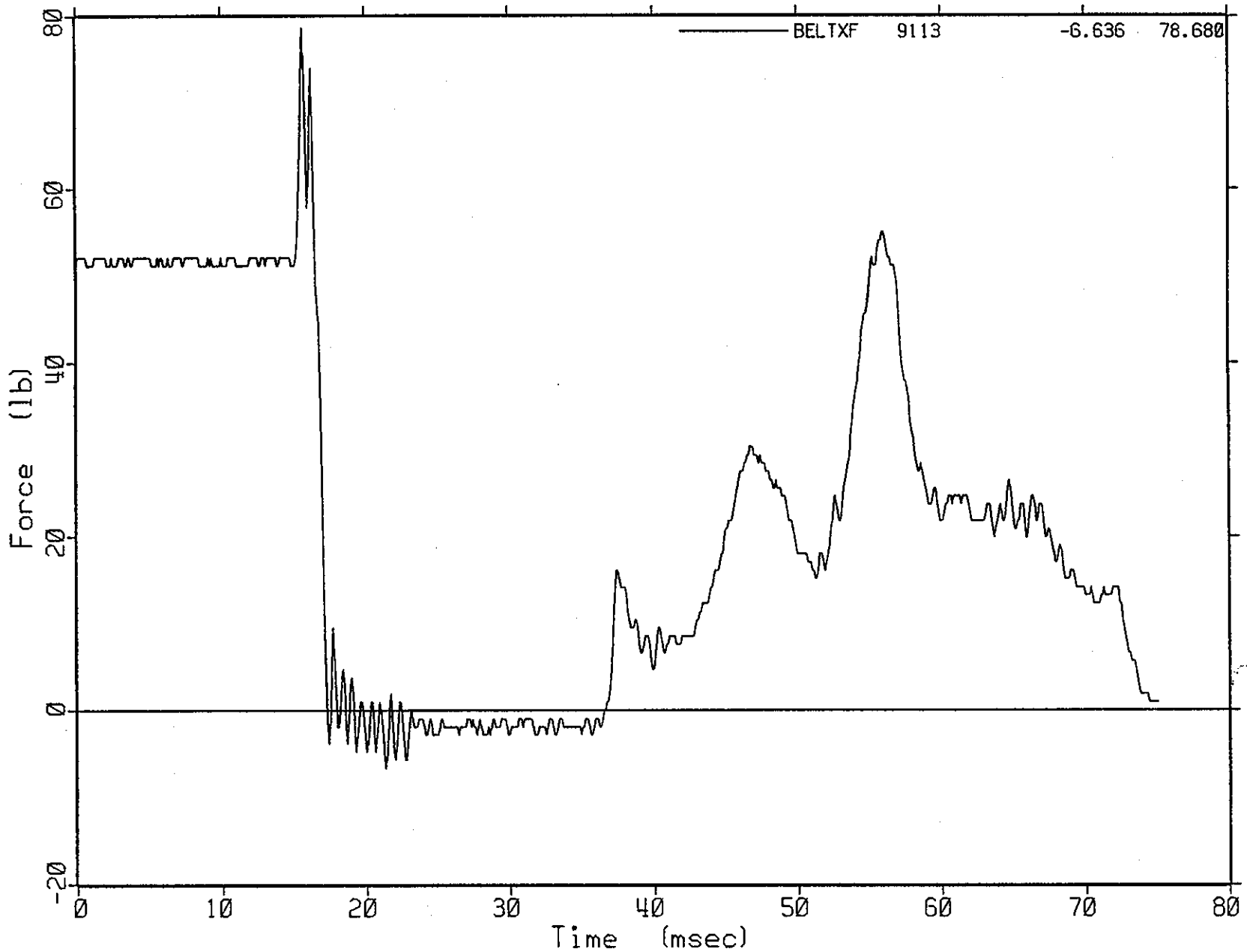
8-OCT-92 17:53



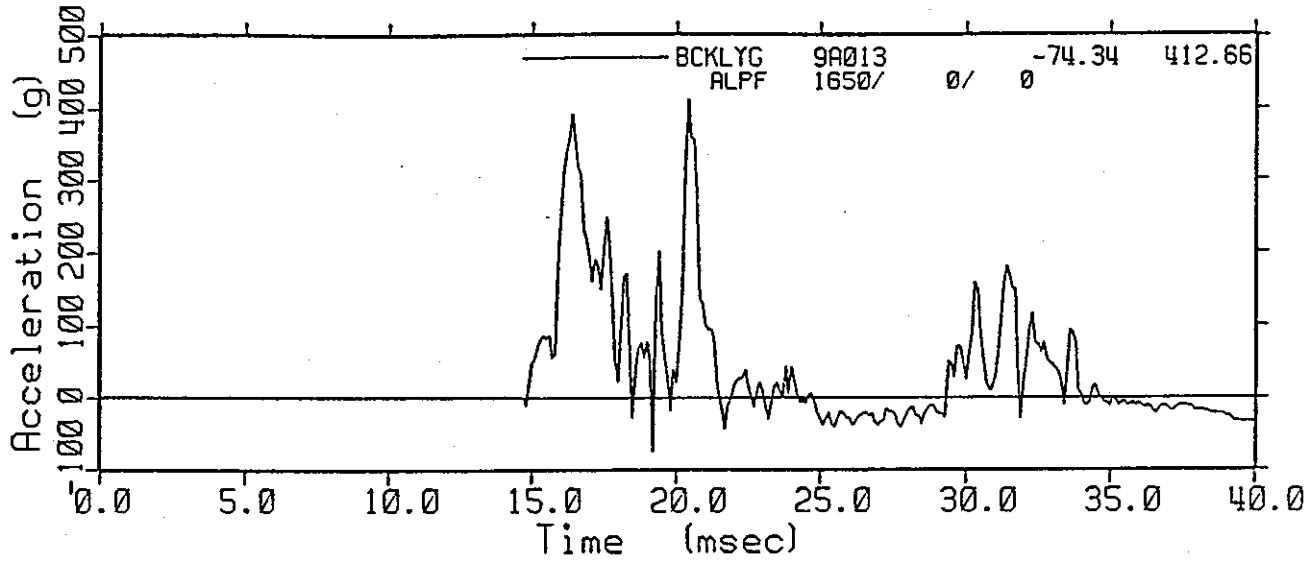
TEST 9113 - FORCE

APPENDIX D

In-Vehicle Safety Belt Buckle Tests

Raw Data

9-OCT-92 20:49



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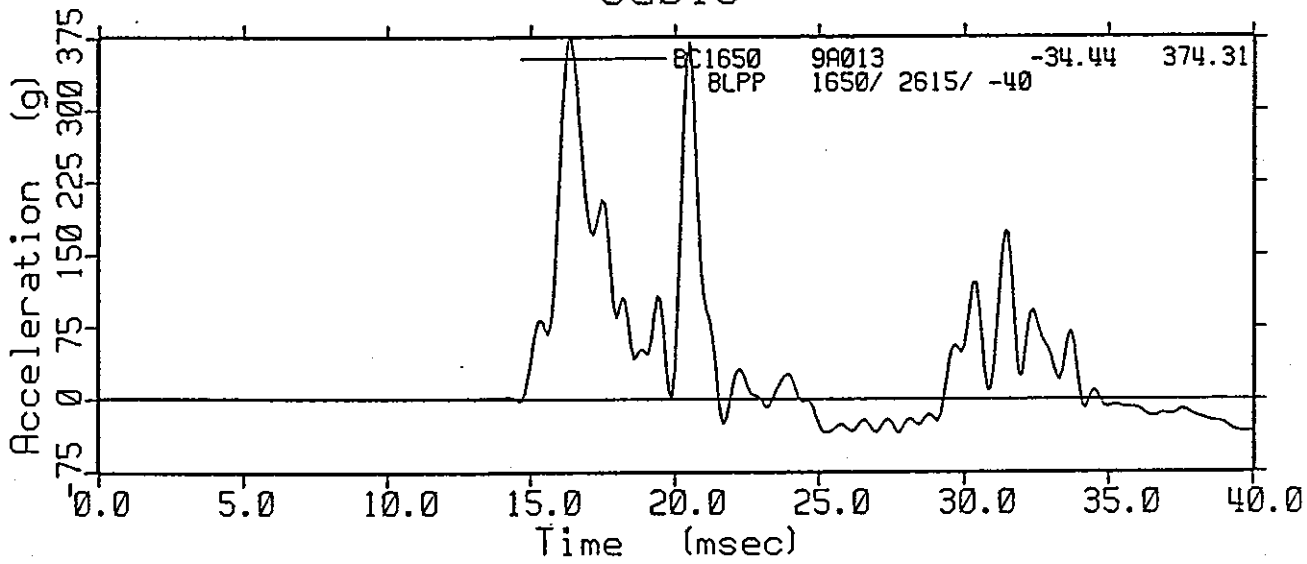

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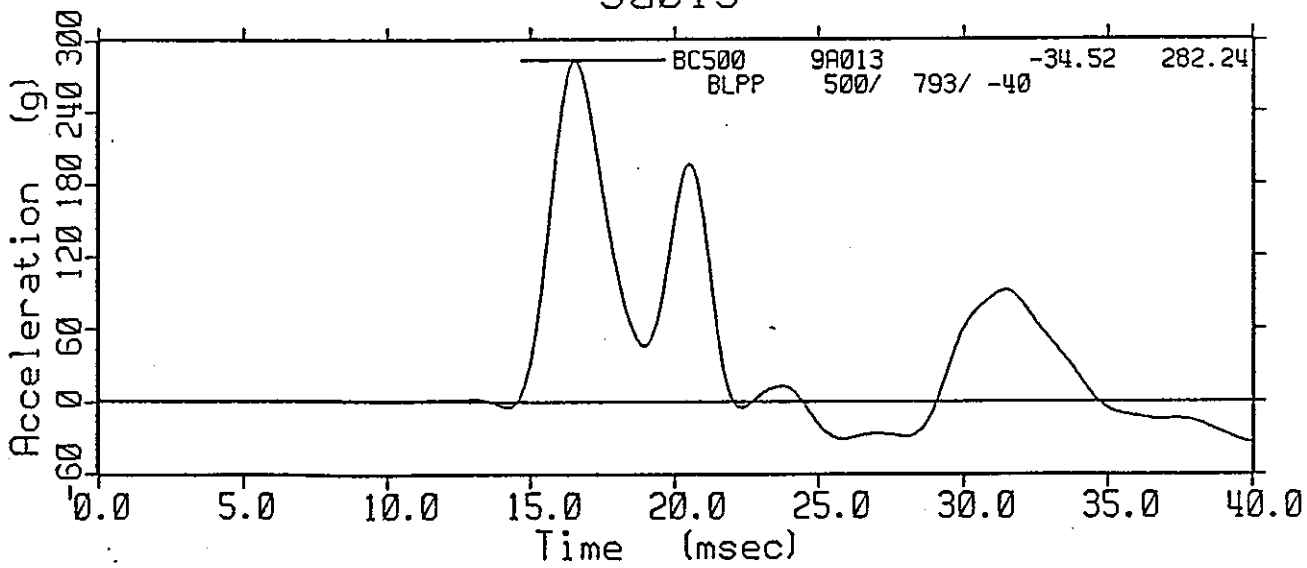
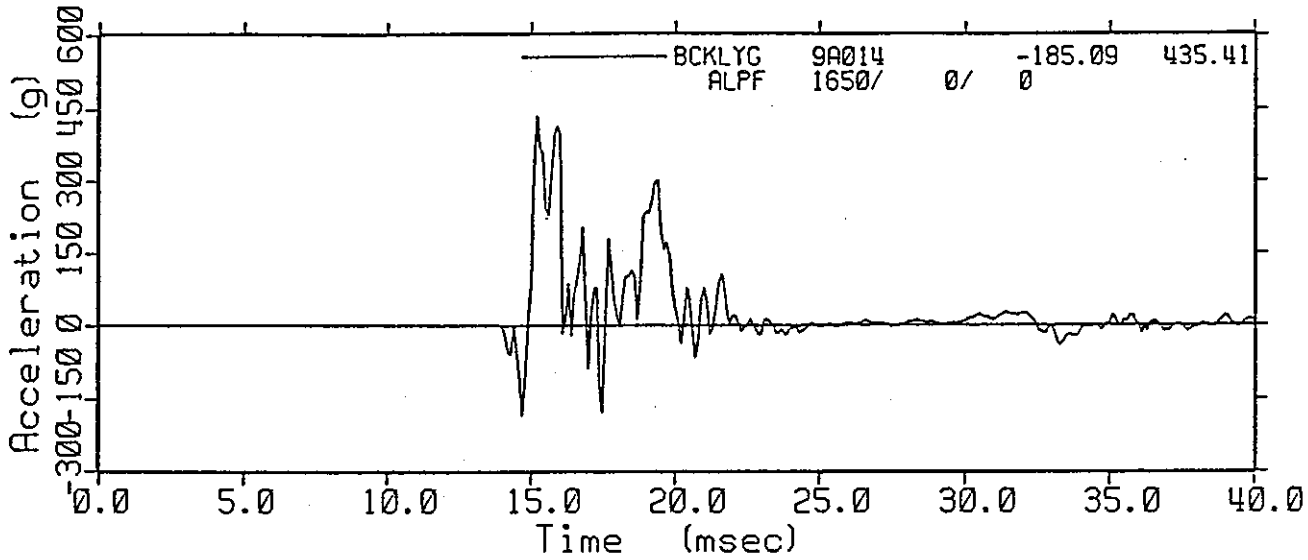


9a013

9-OCT-92 20:49



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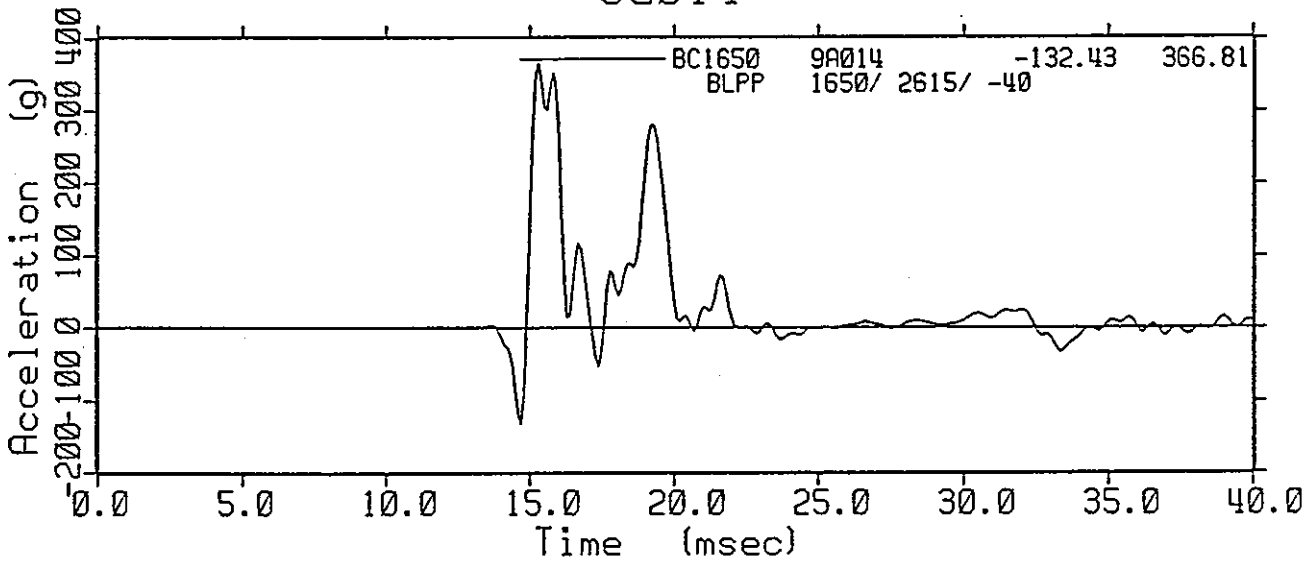

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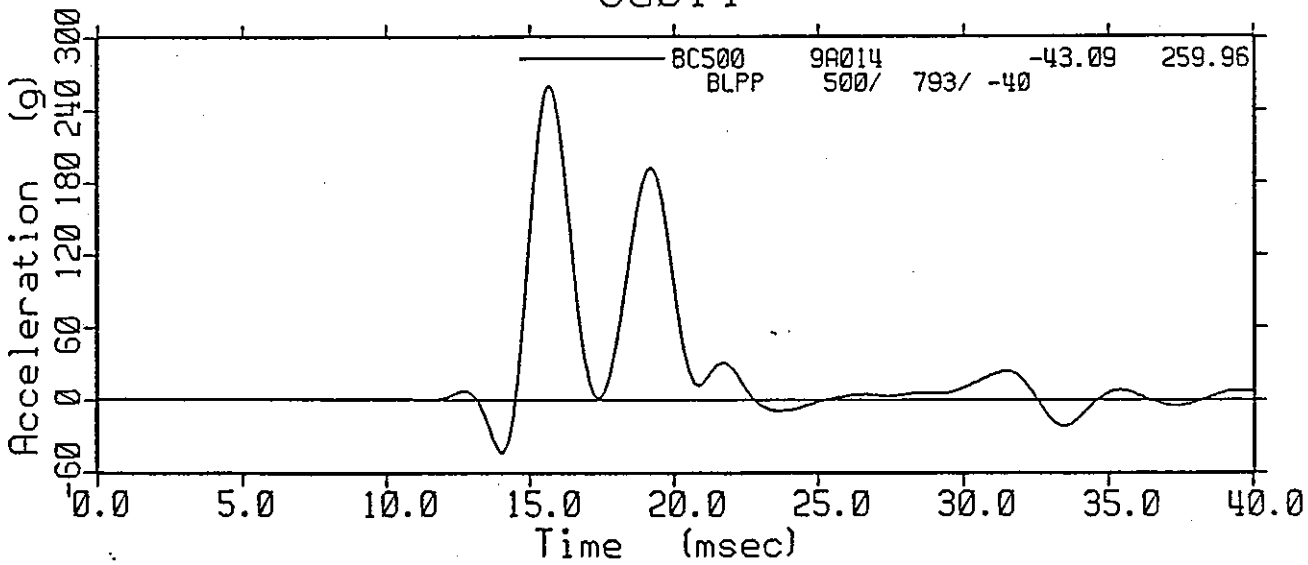
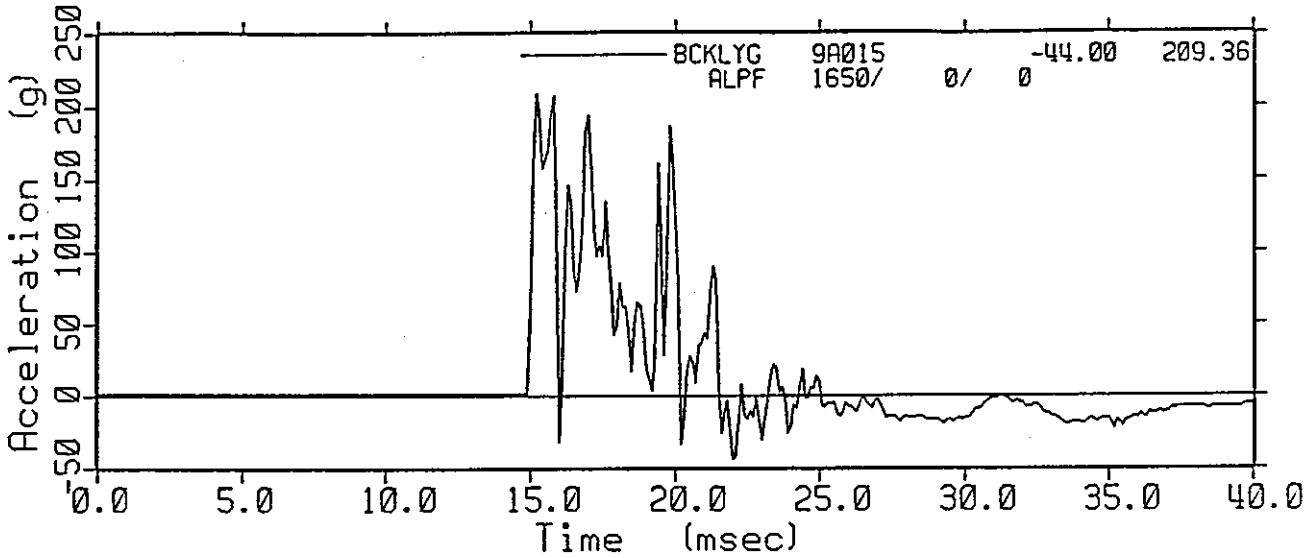


9a014

9-OCT-92 20:49



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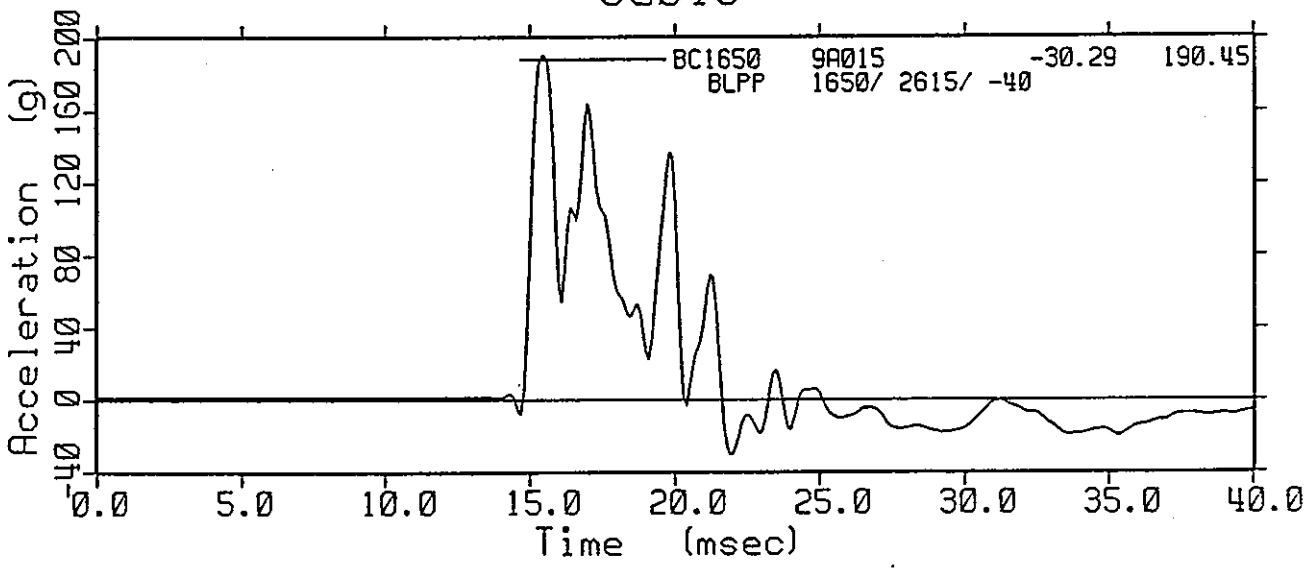

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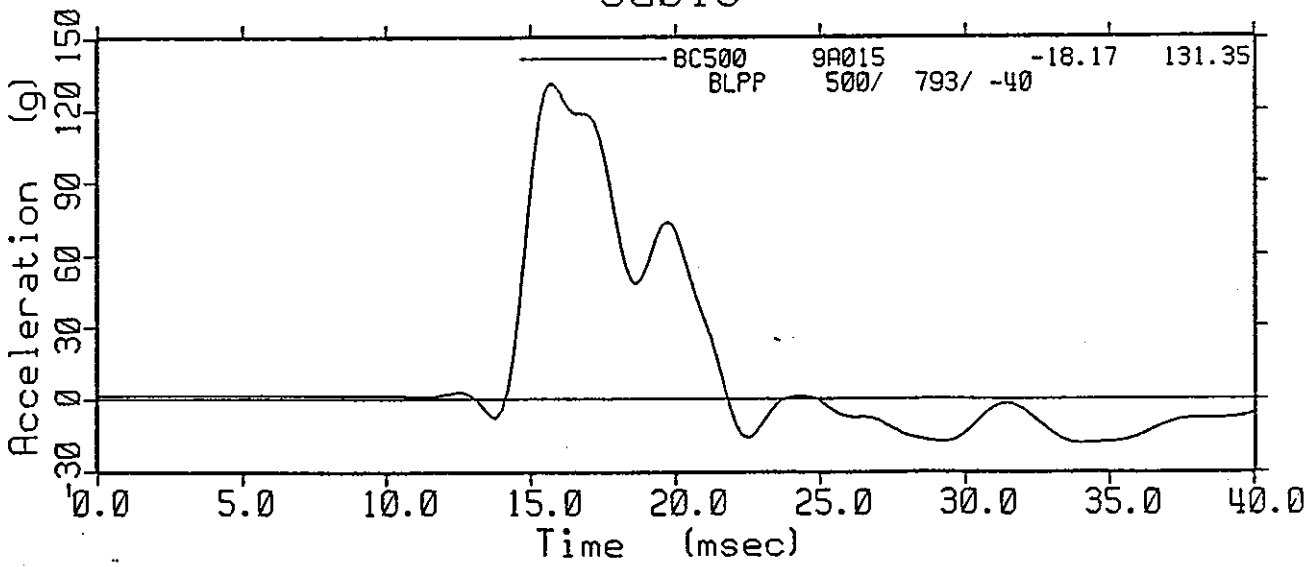
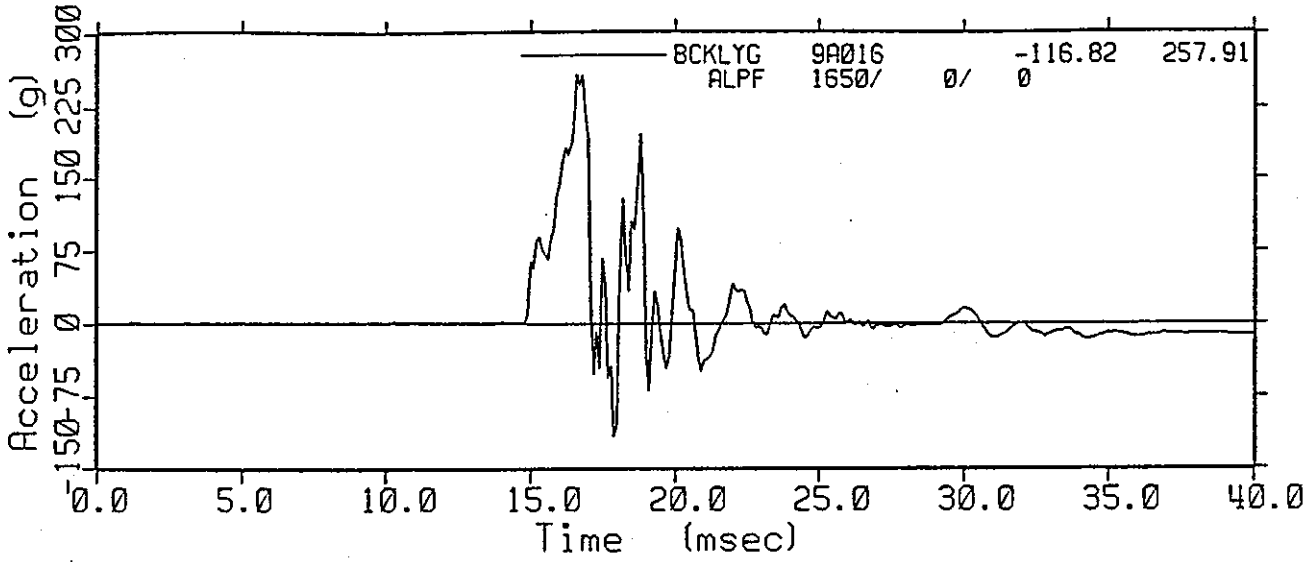


9a015

9-OCT-92 20:49



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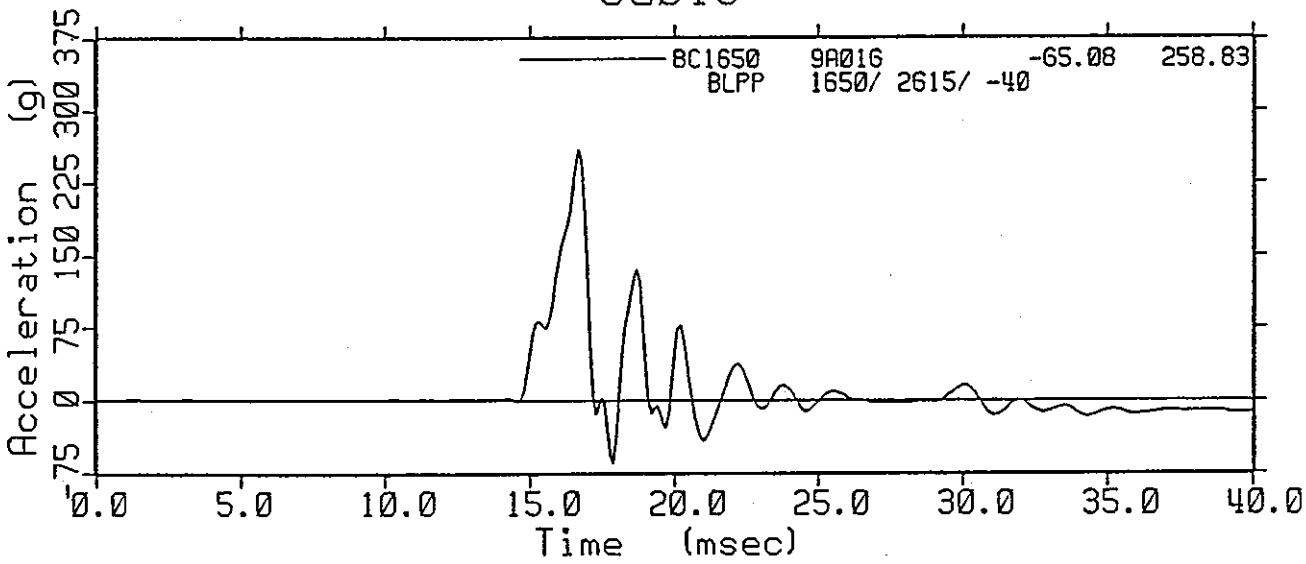

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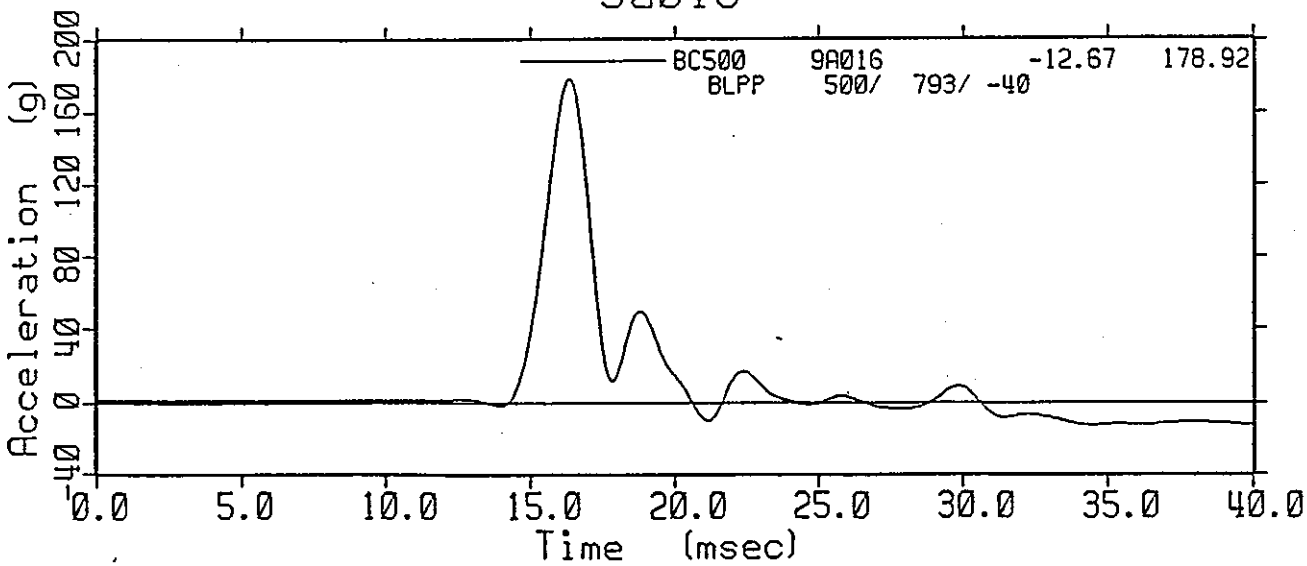

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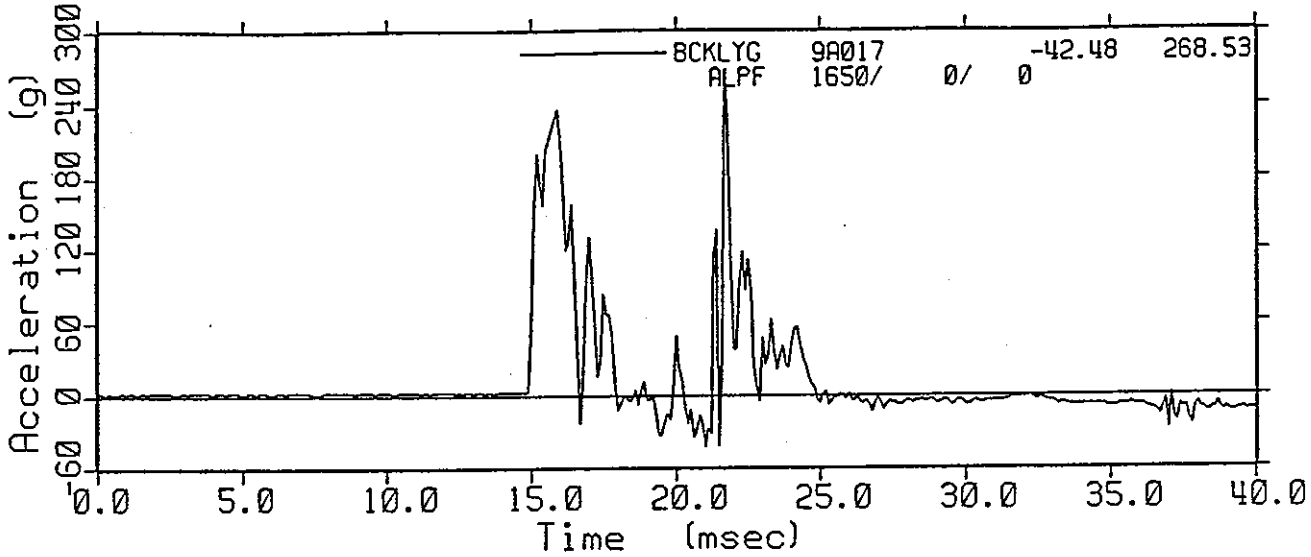
9-OCT-92 20:49



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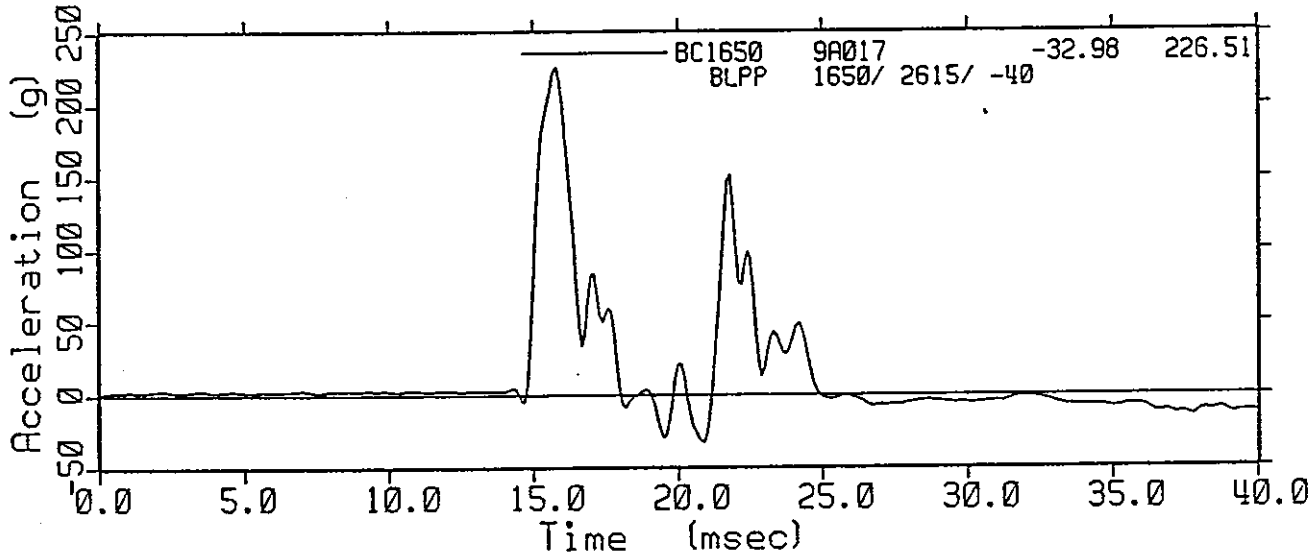

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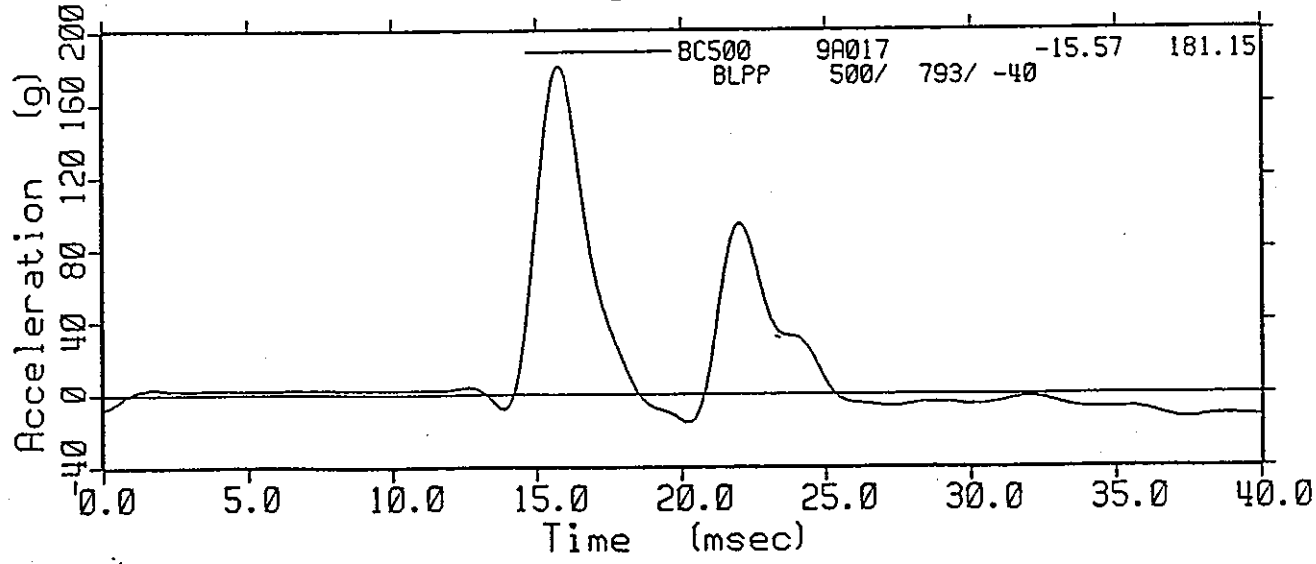

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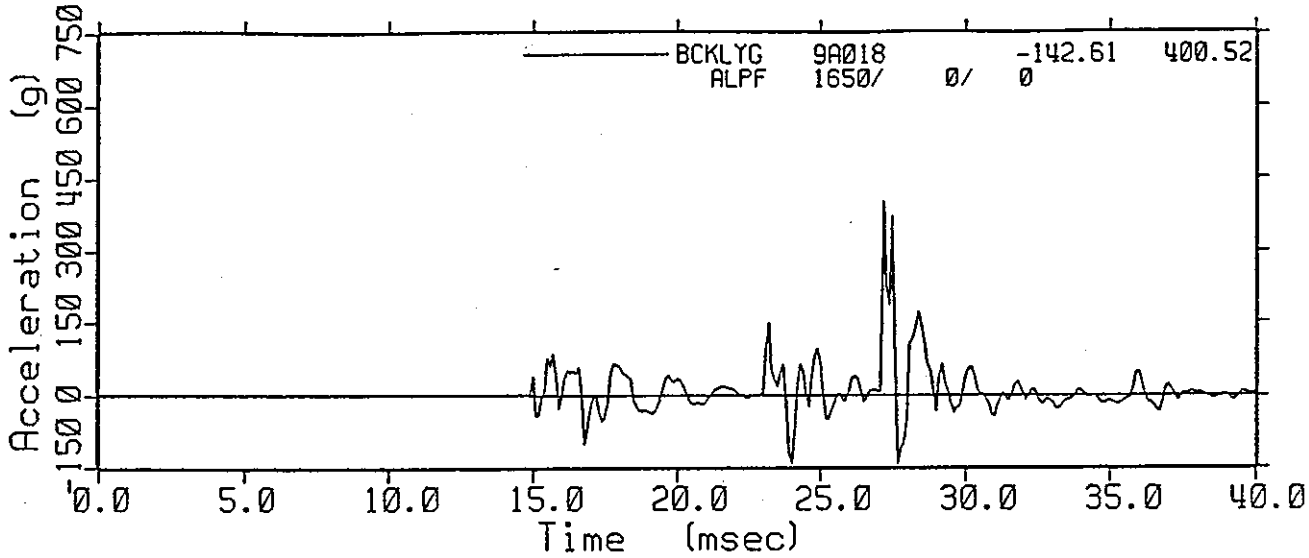

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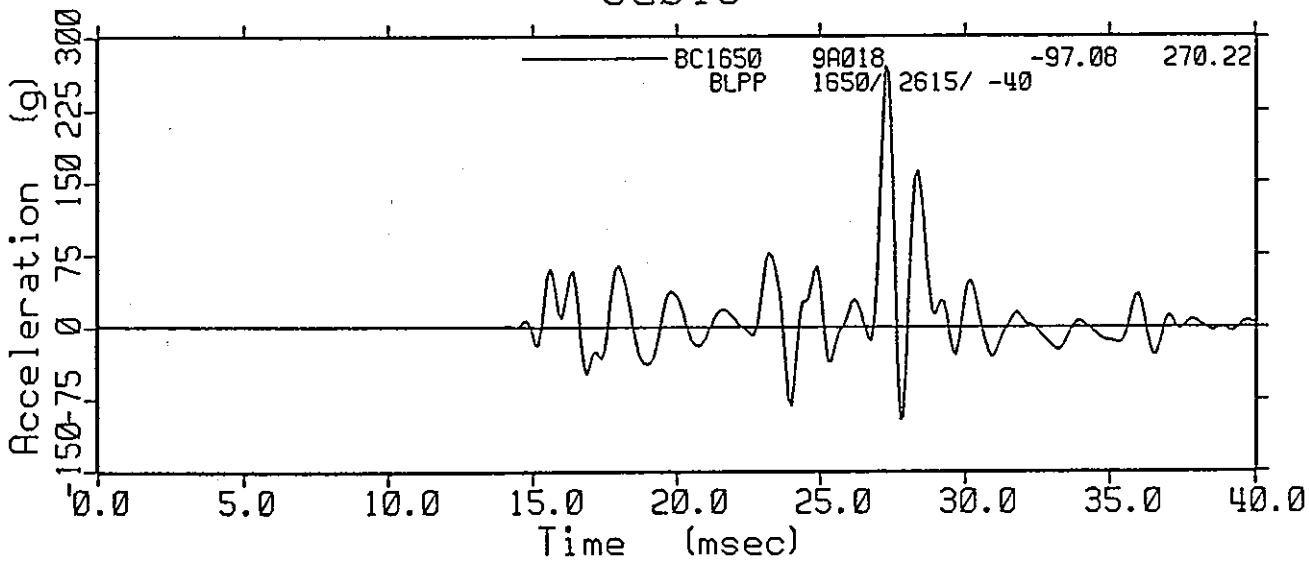

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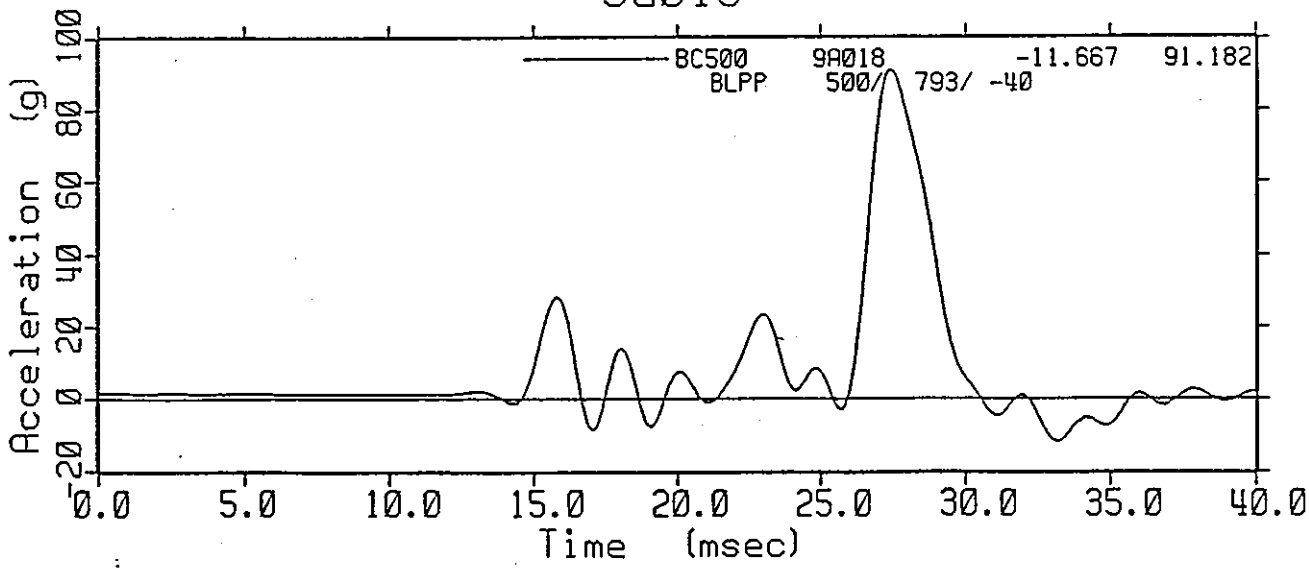

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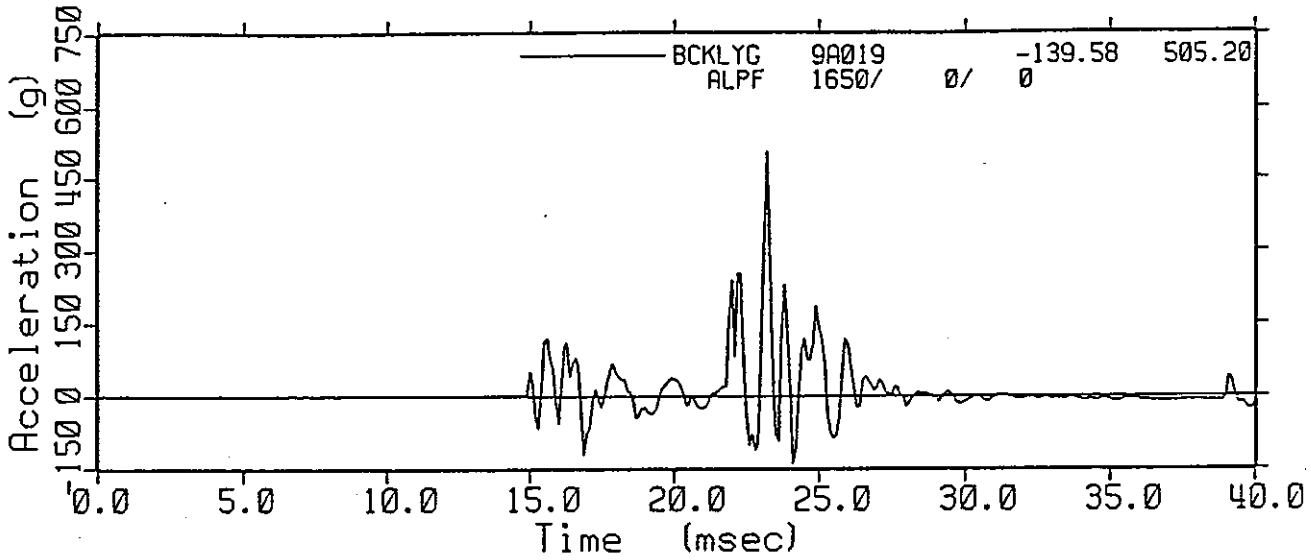

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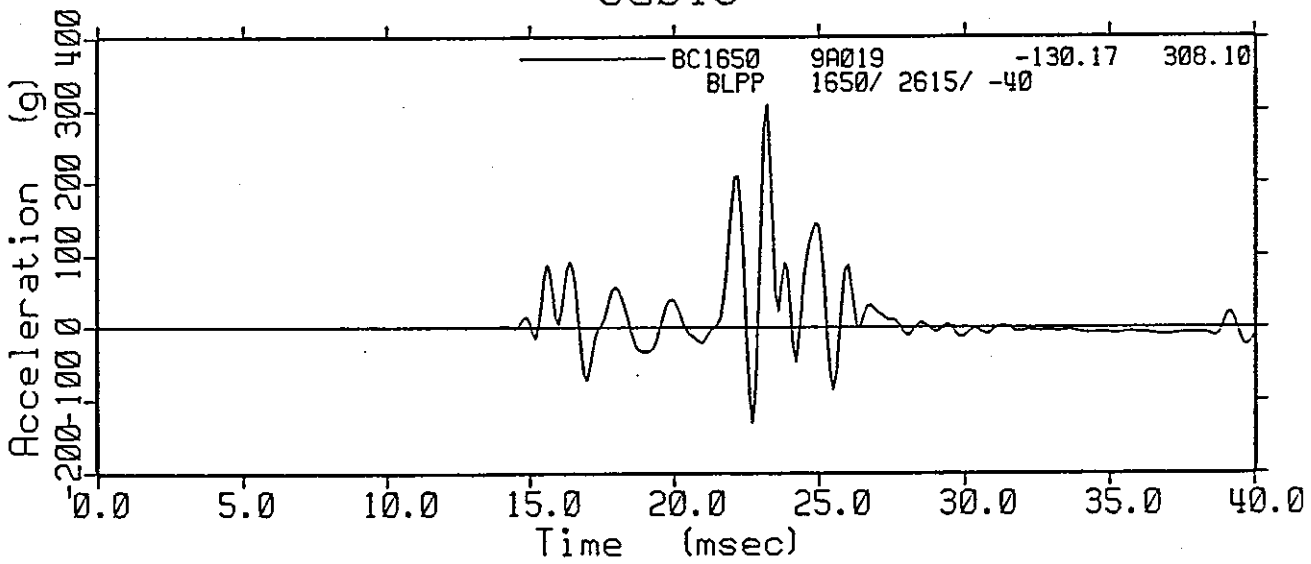

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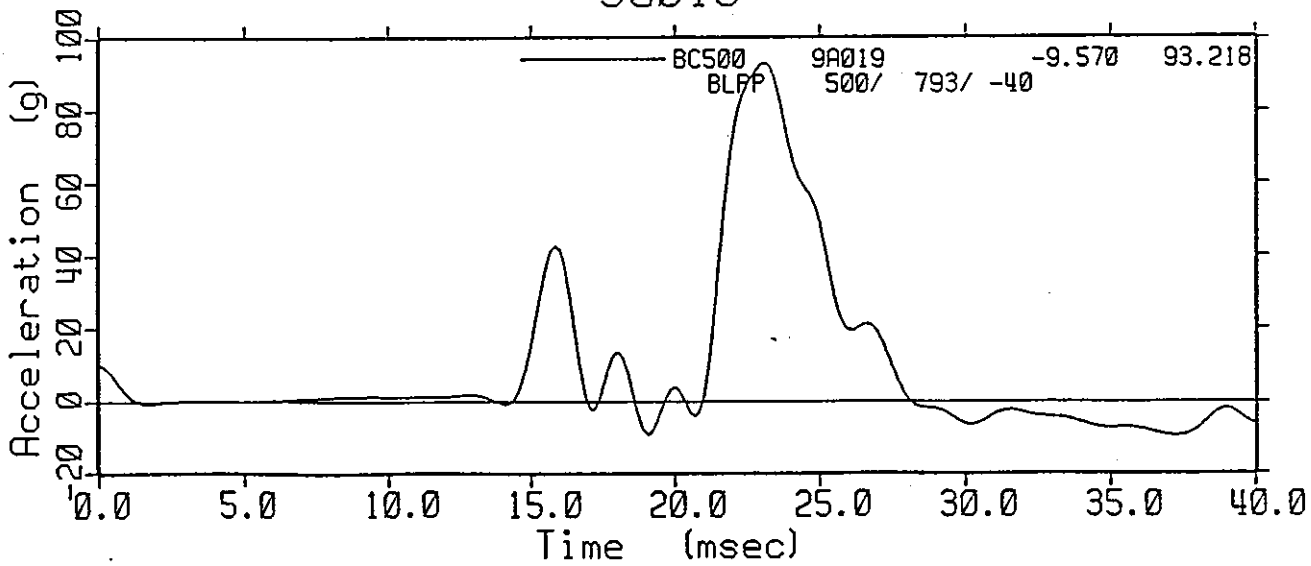

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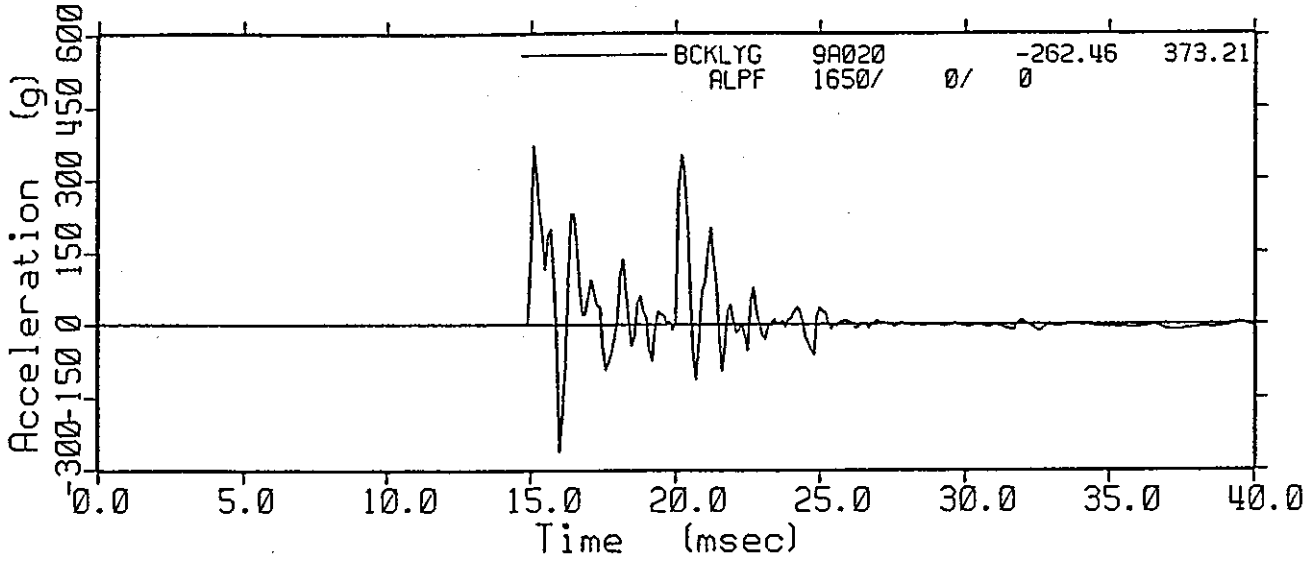

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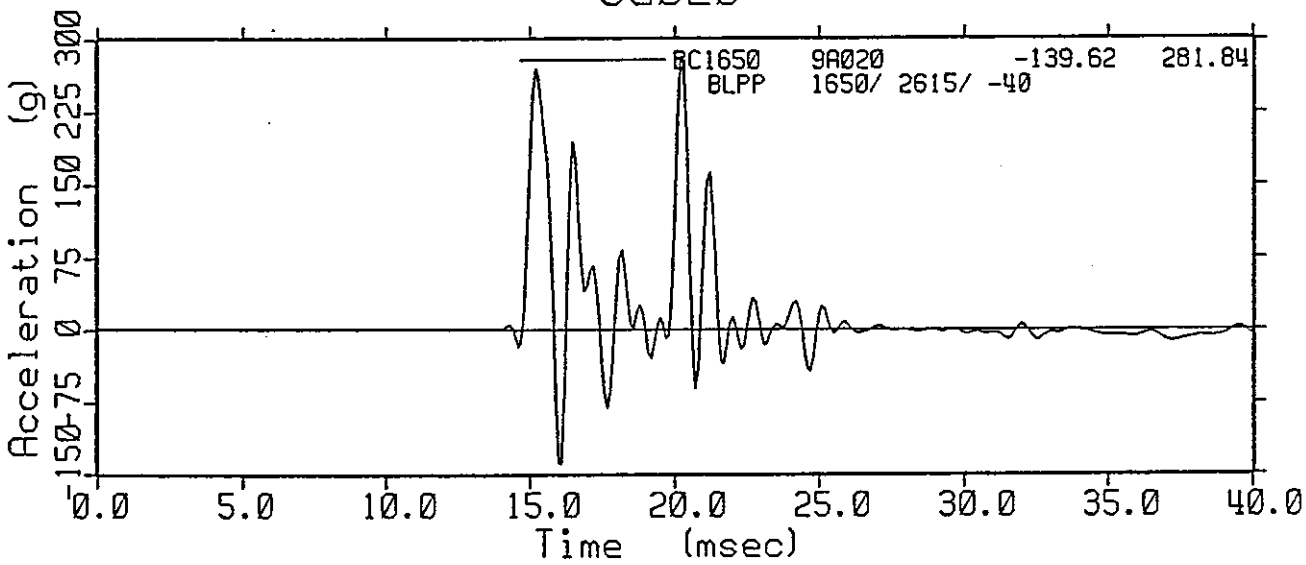

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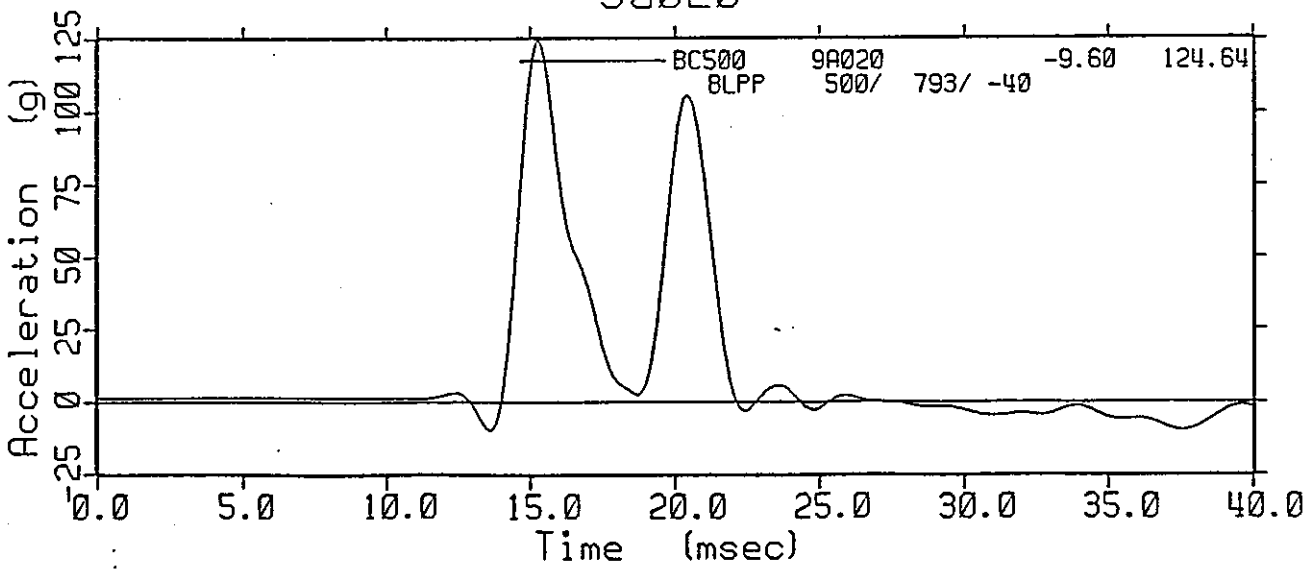

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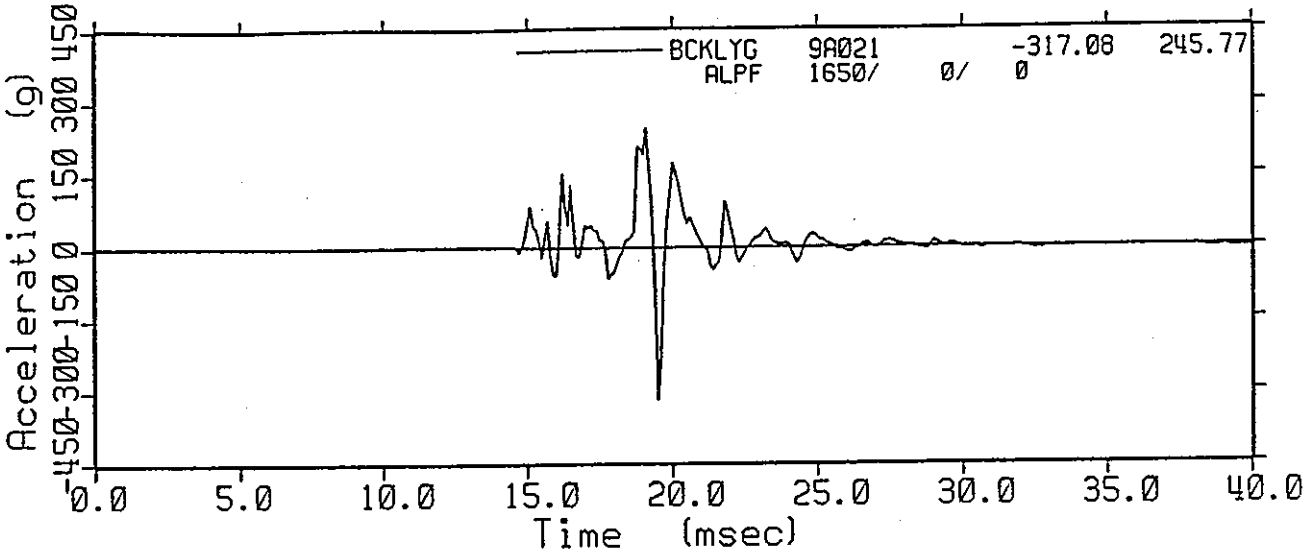

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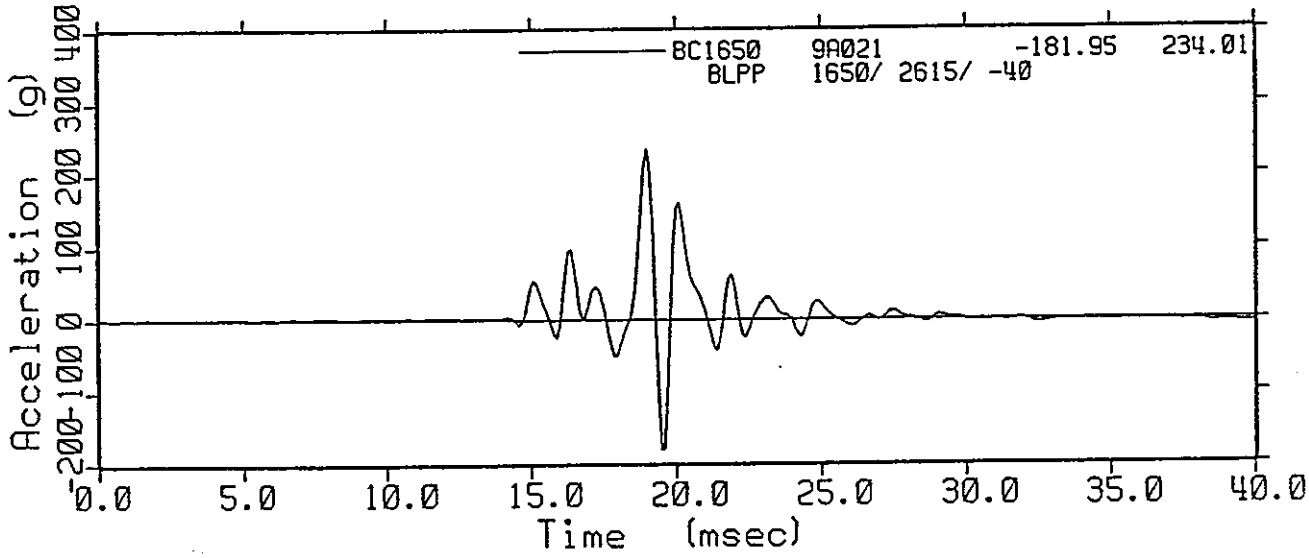

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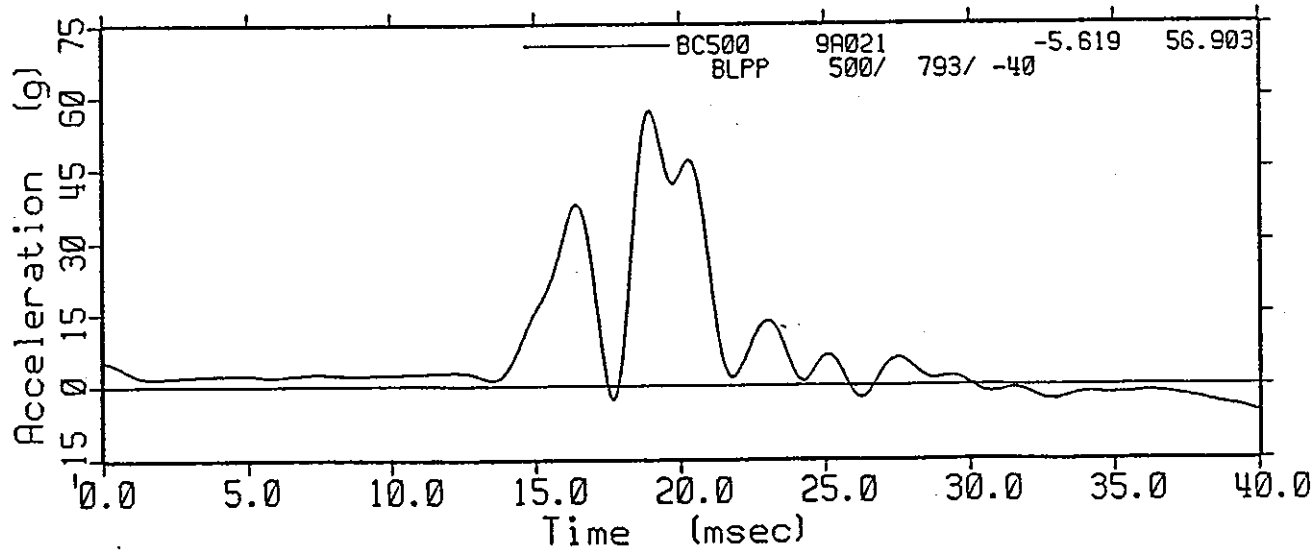

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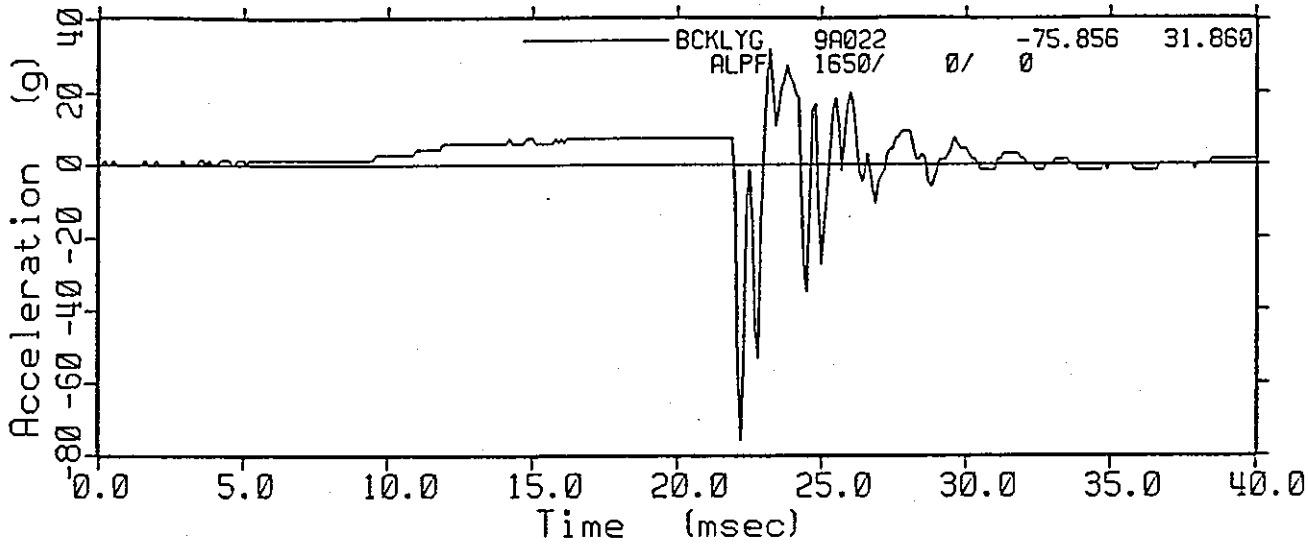

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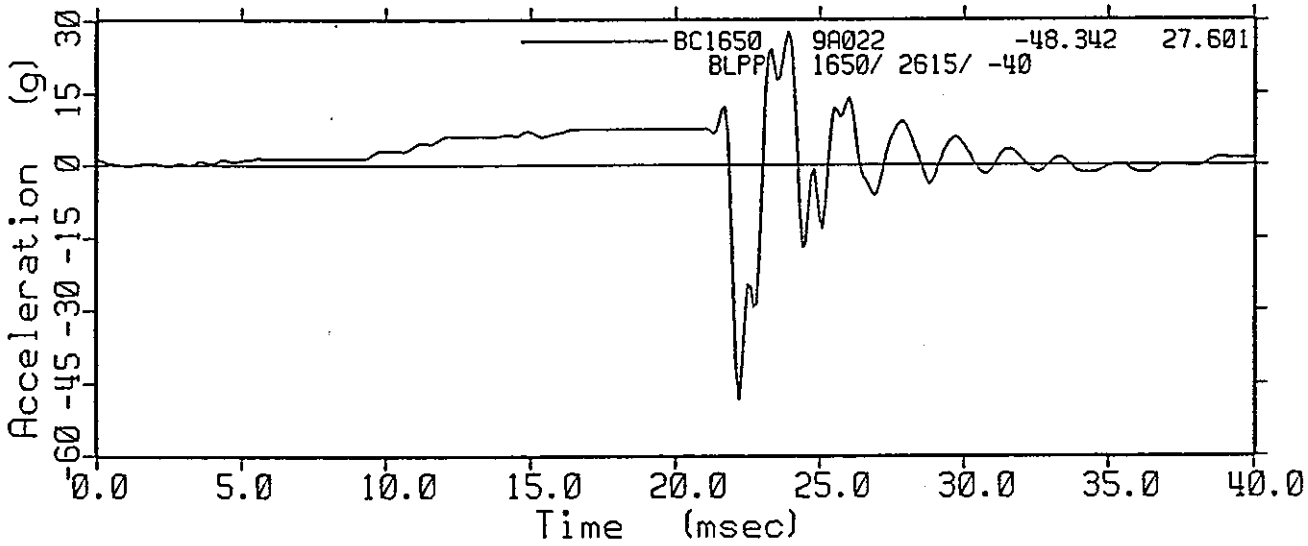

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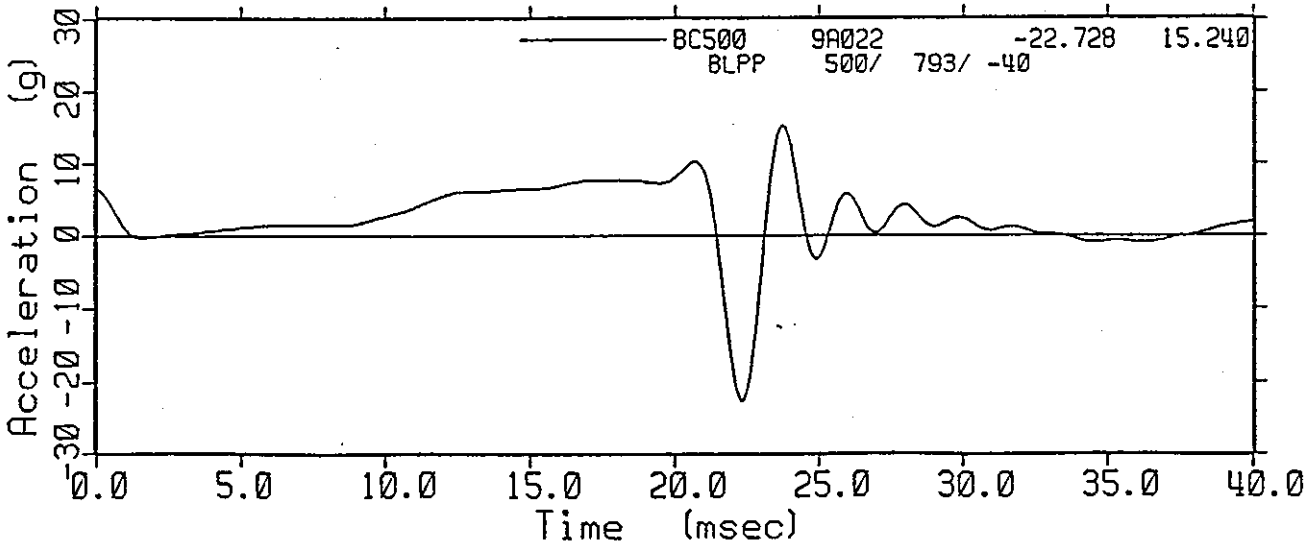

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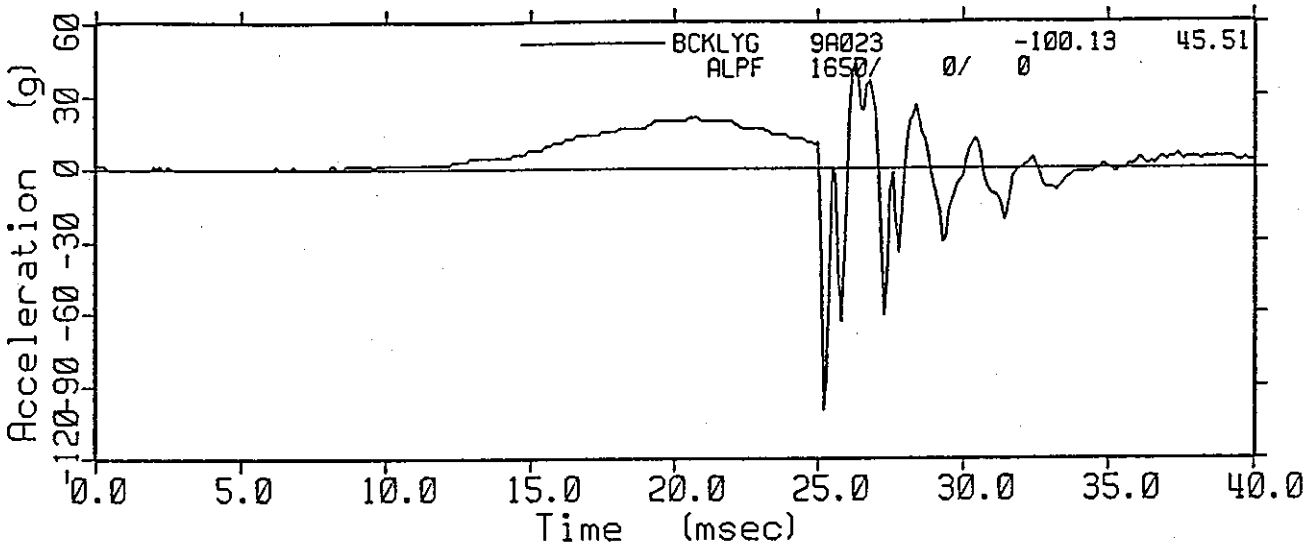

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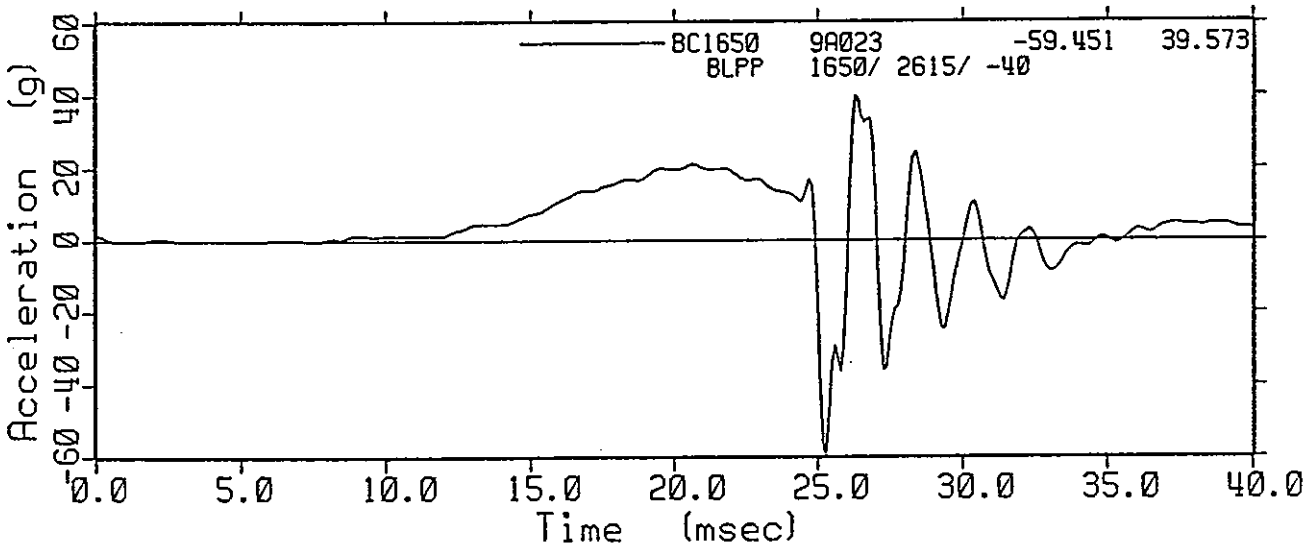

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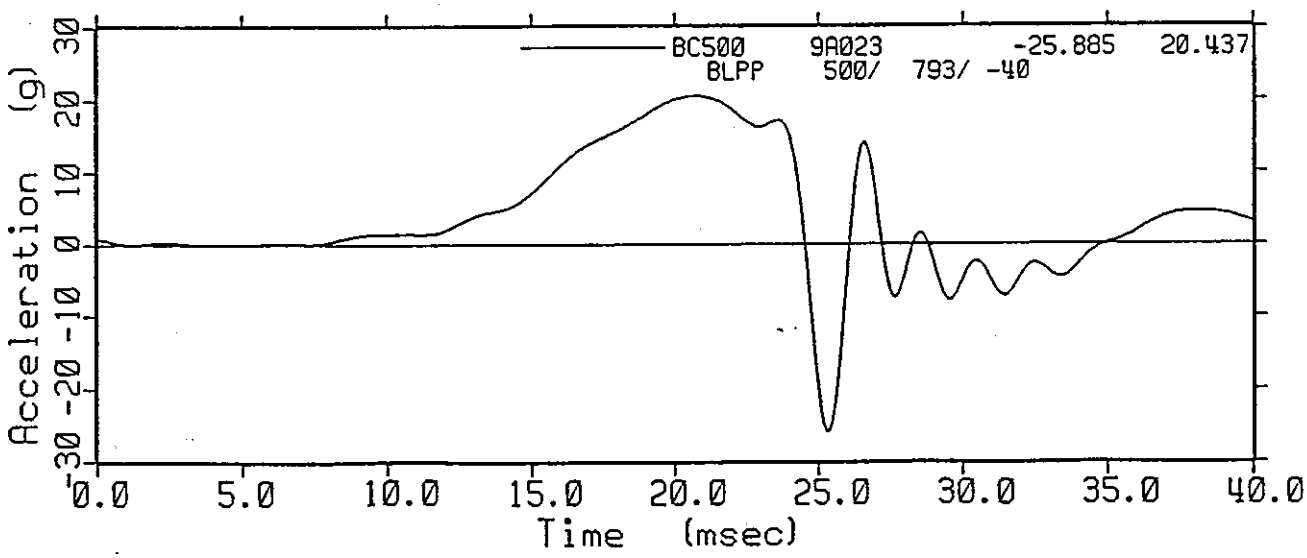

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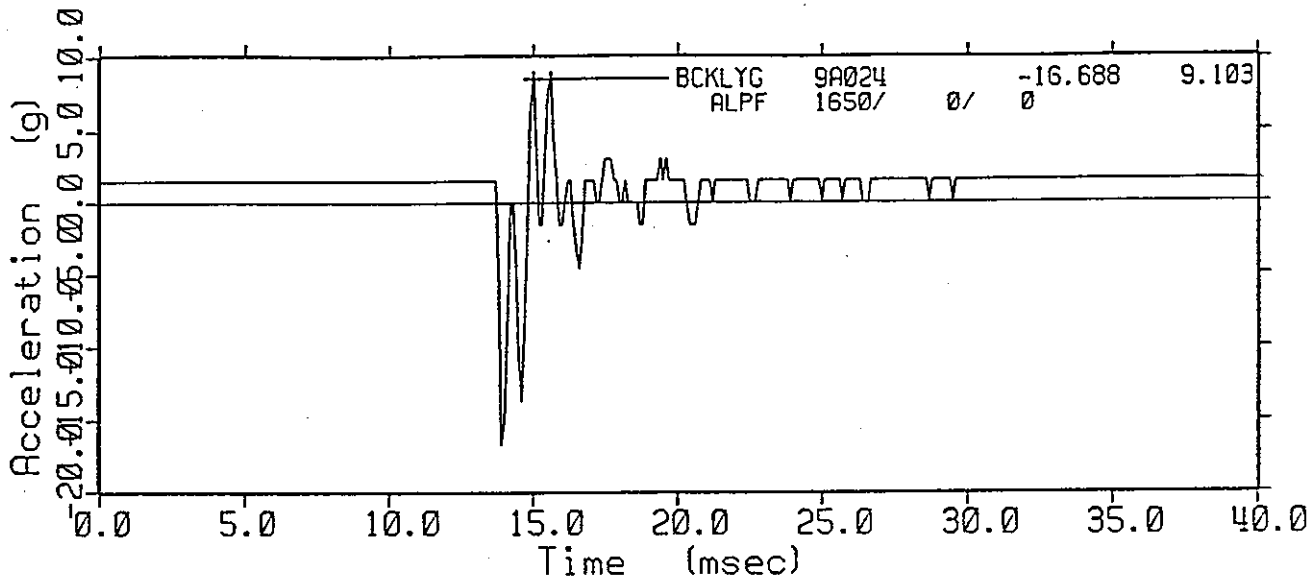

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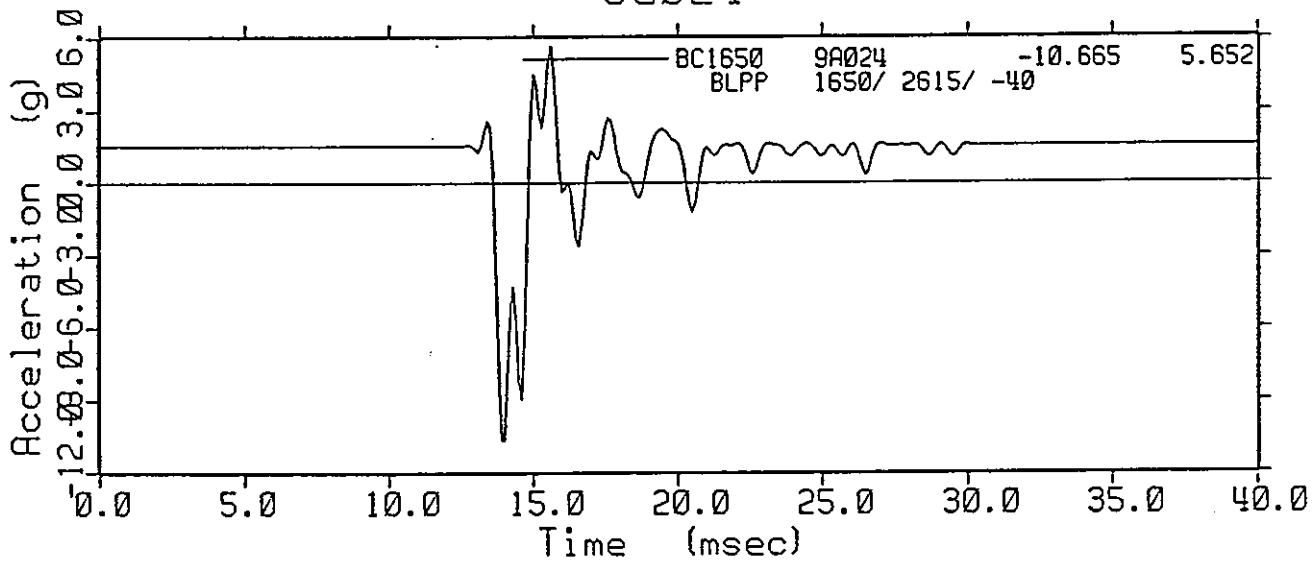

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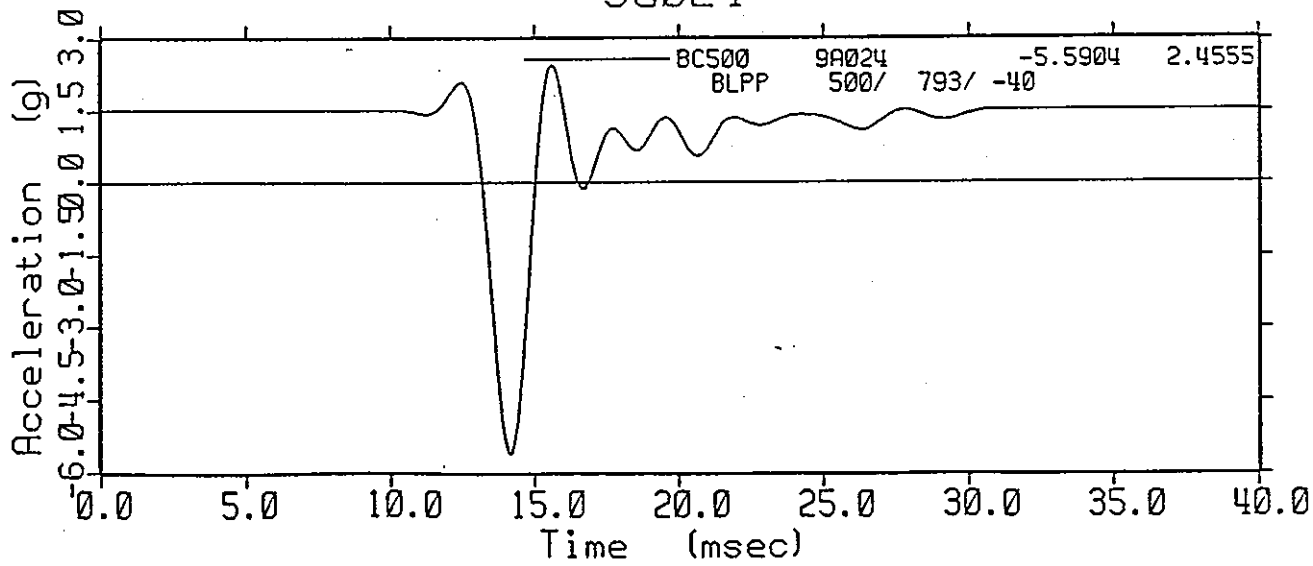

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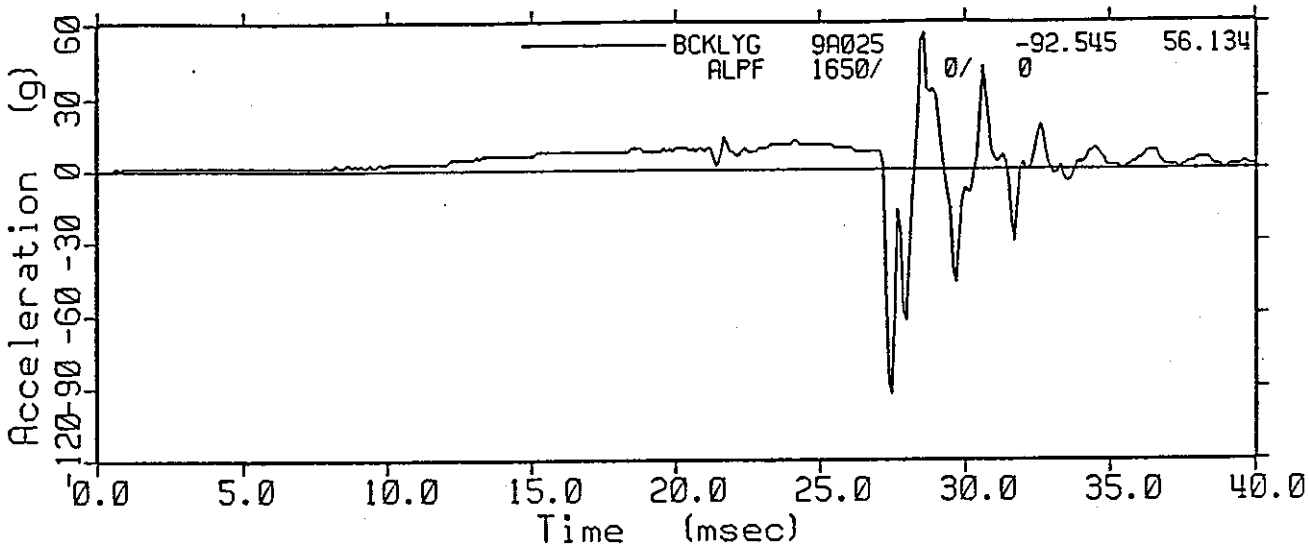

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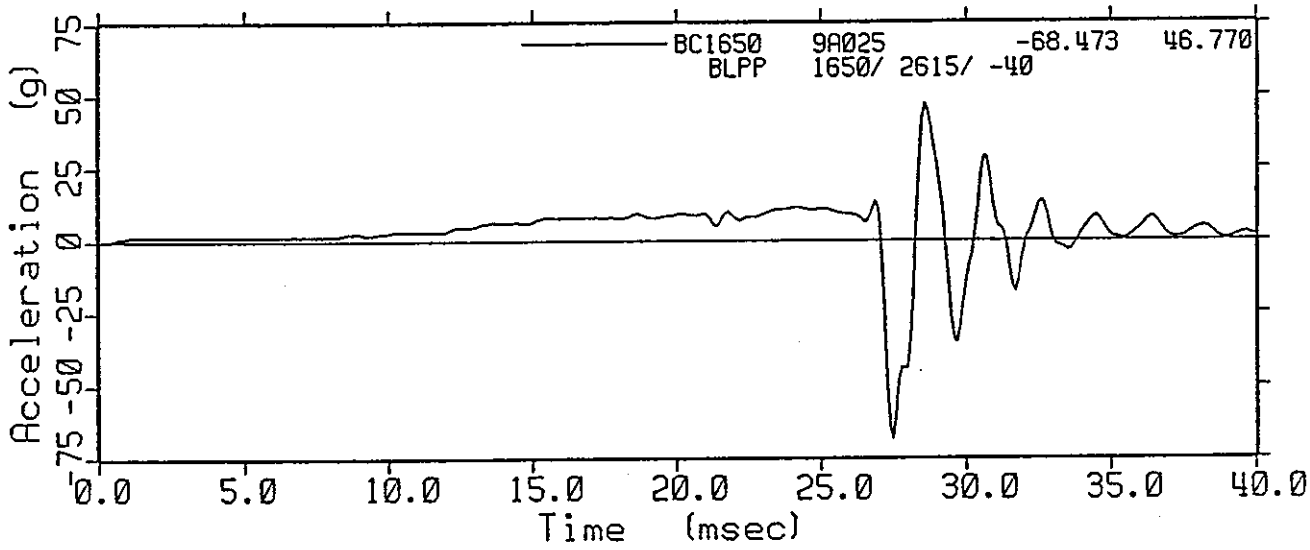

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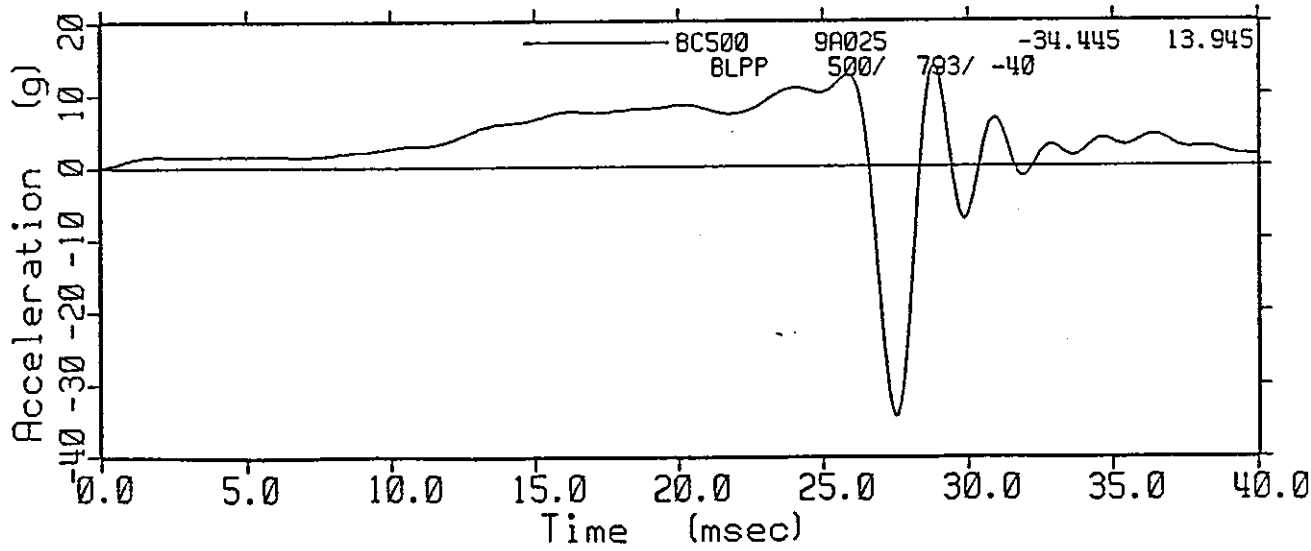

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APPENDIX E

Vehicle Crash Test Raw Data

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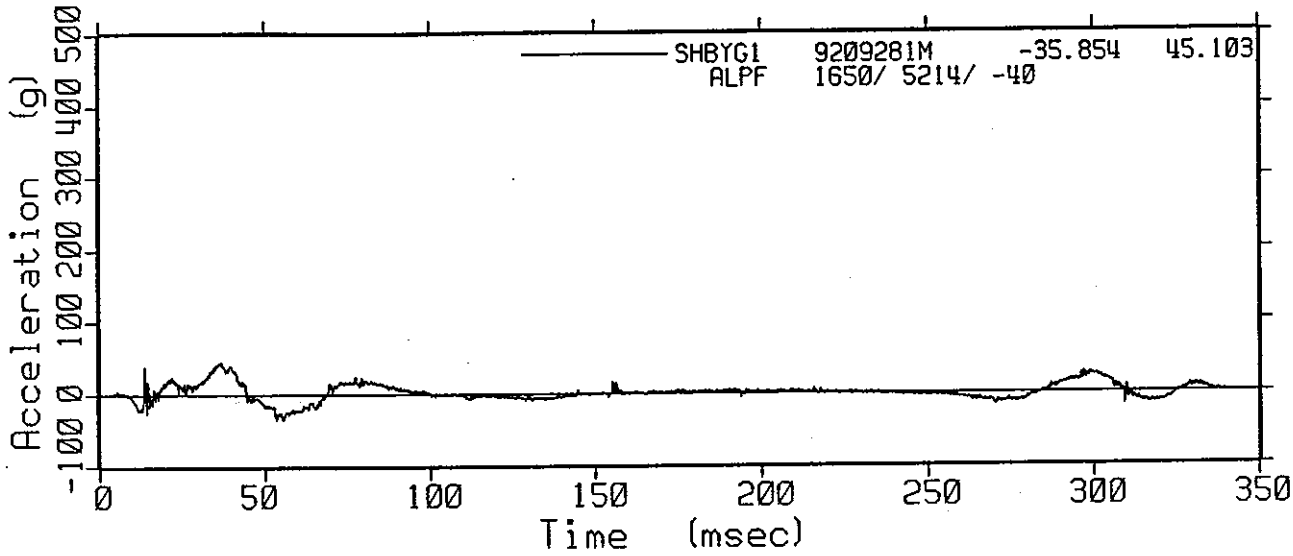
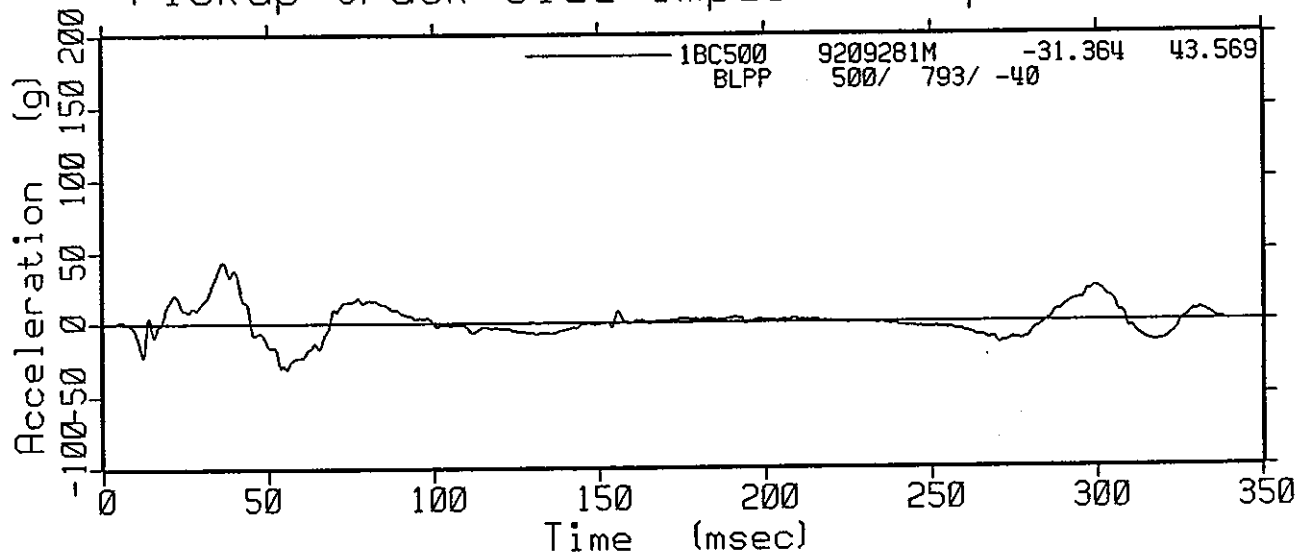
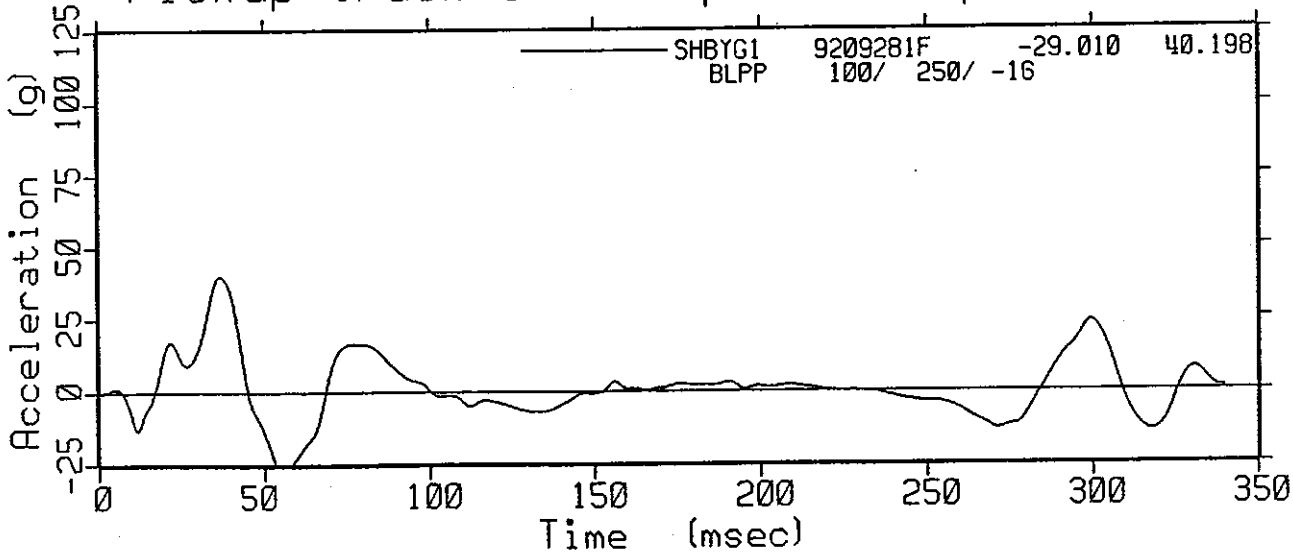


Pickup truck side impact 20 mph driver

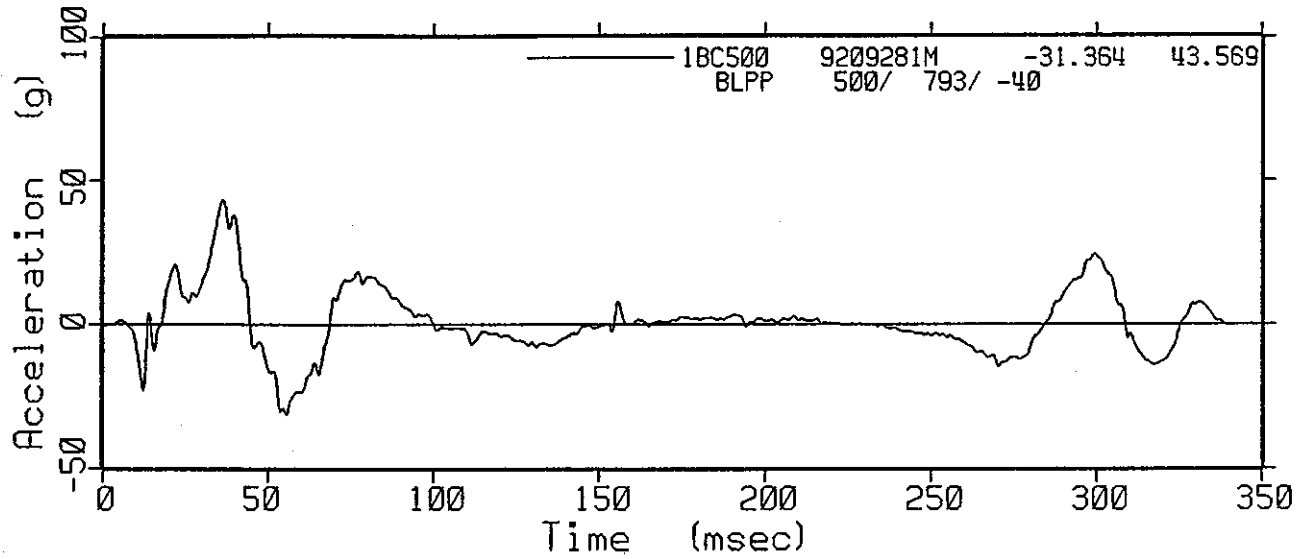


Pickup truck side impact 20 mph driver

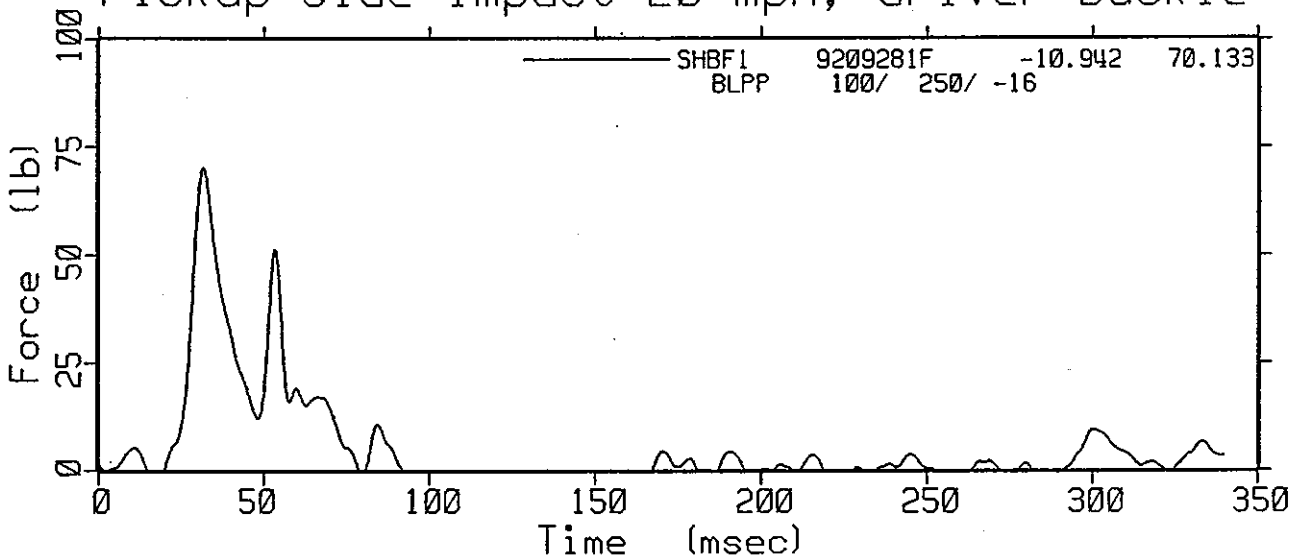


Pickup truck side impact 20 mph driver

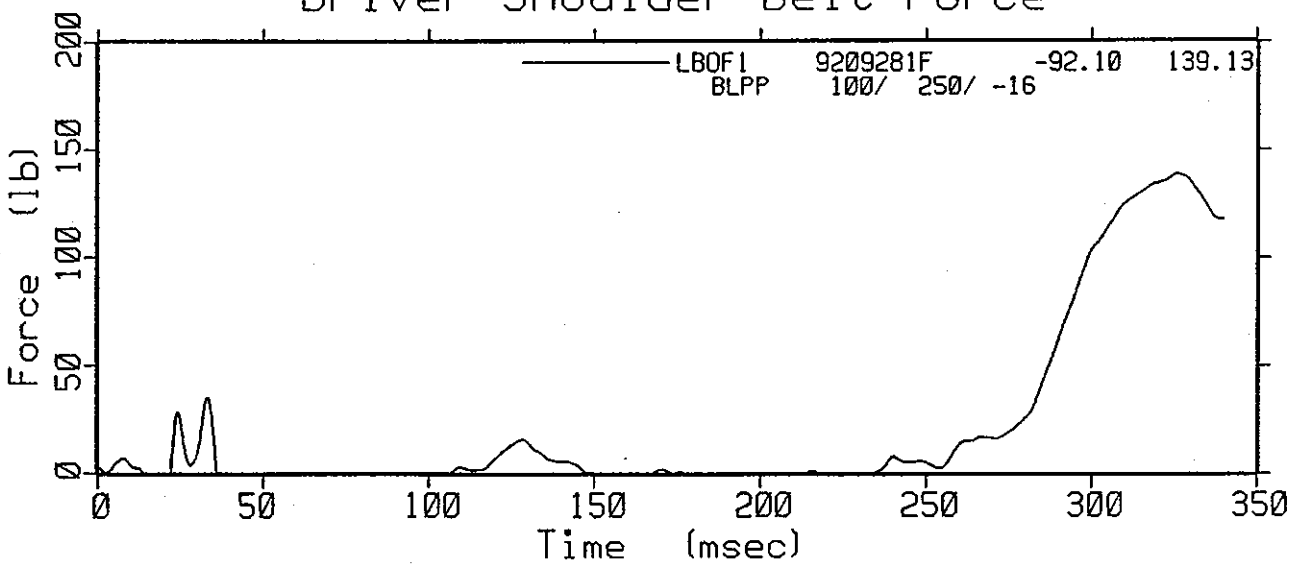
6-NOV-92 09:50



Pickup side impact 20 mph, driver buckle

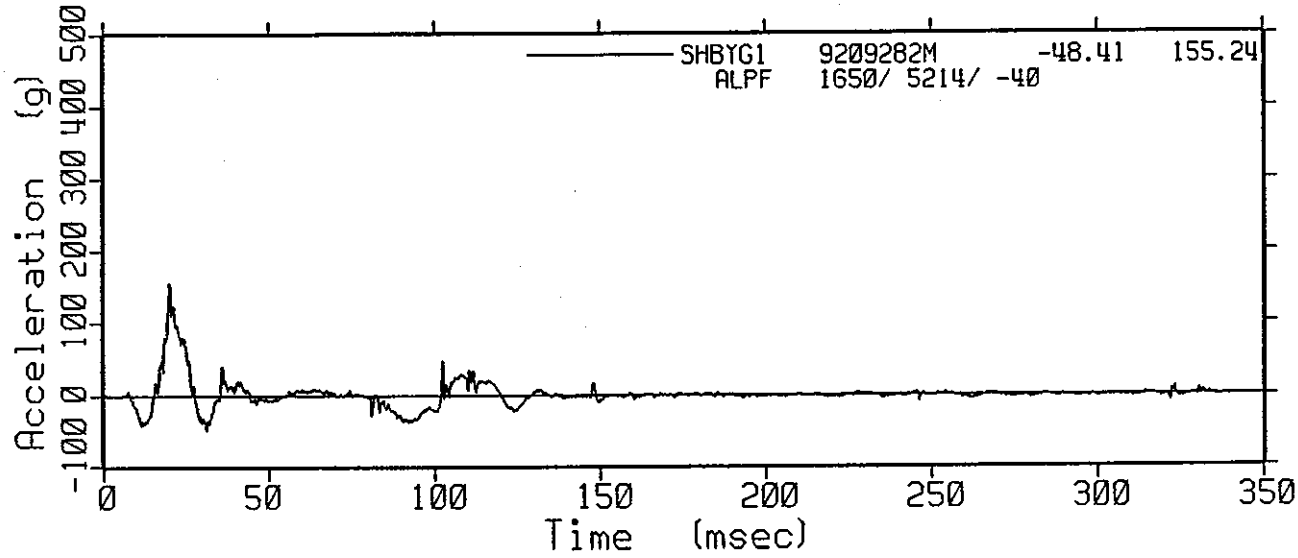


Driver Shoulder Belt Force

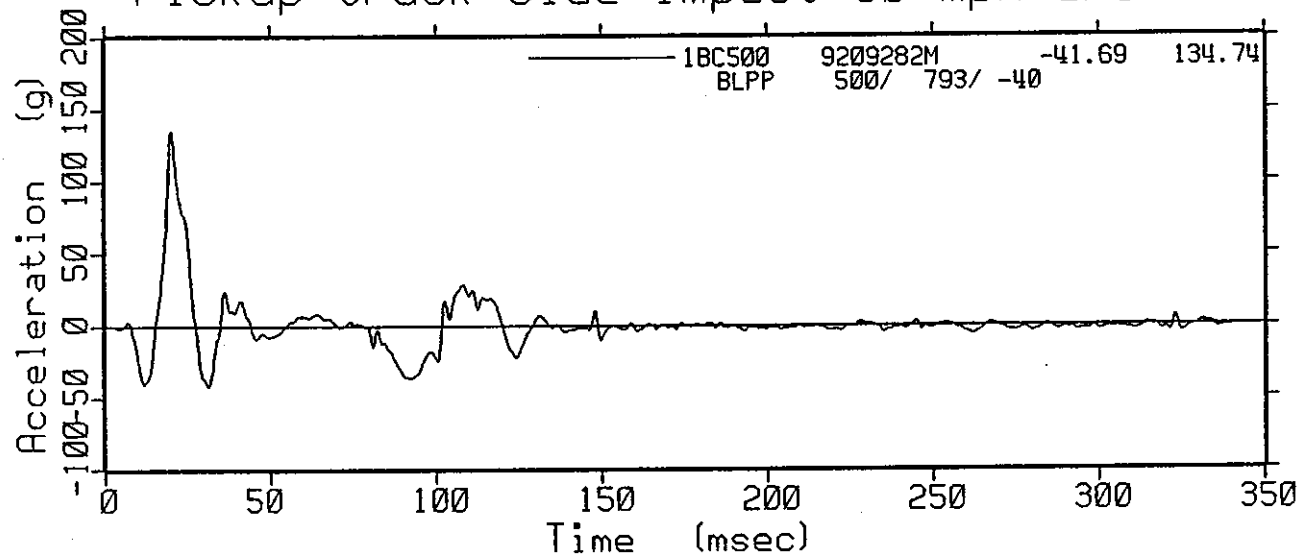


Driver Lap Belt Force

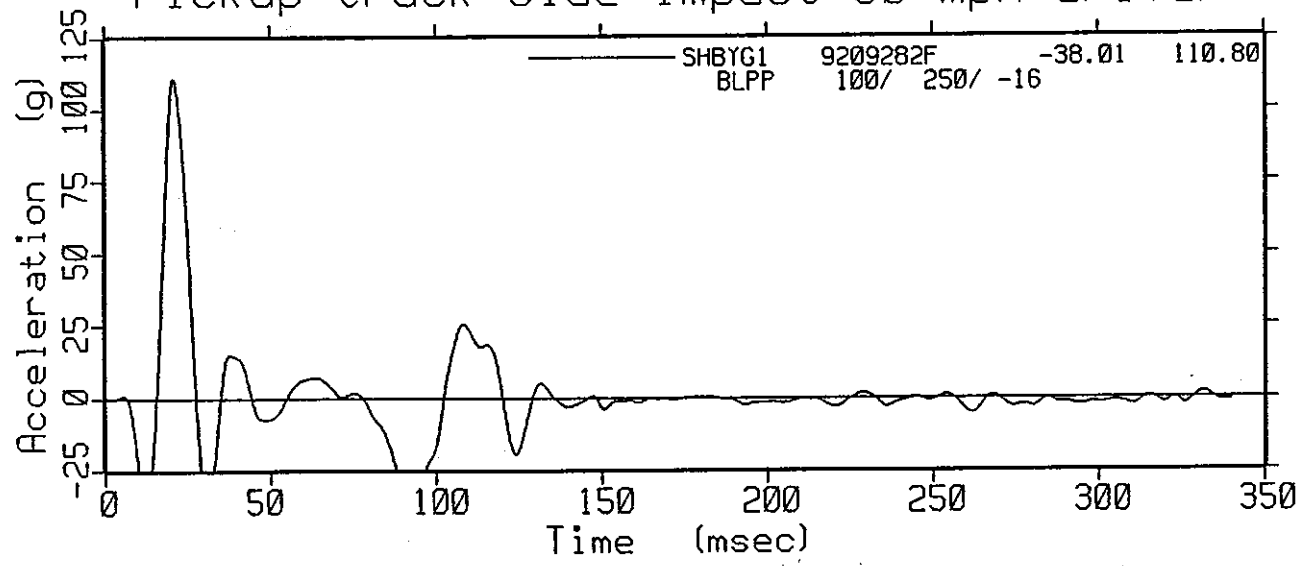
3-NOV-92 15:00



Pickup truck side impact 30 mph driver

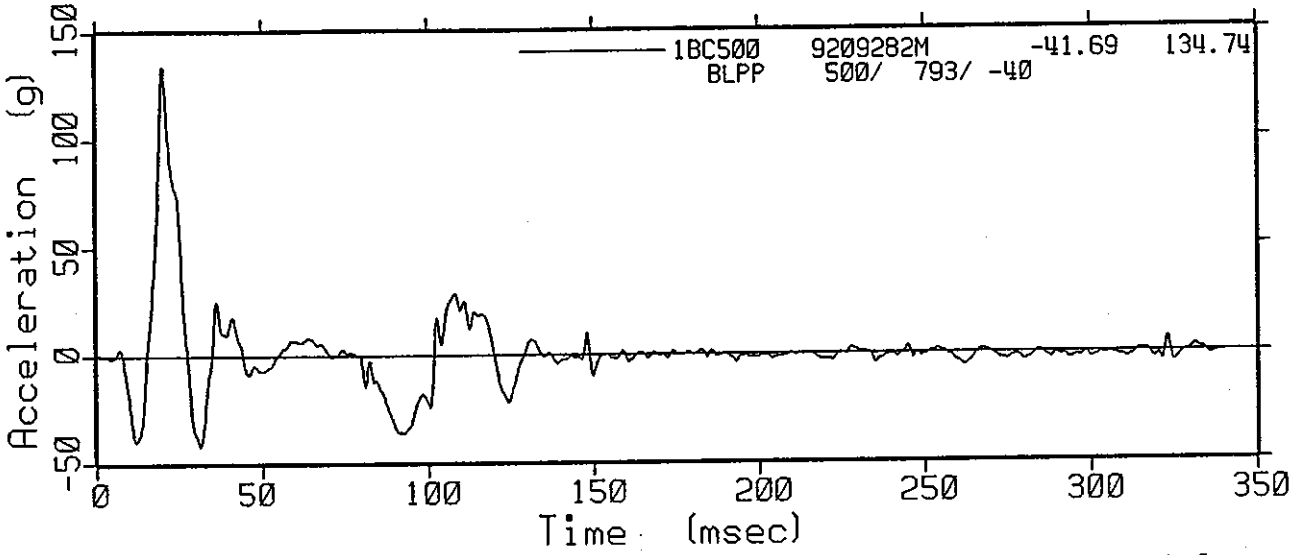


Pickup truck side impact 30 mph driver

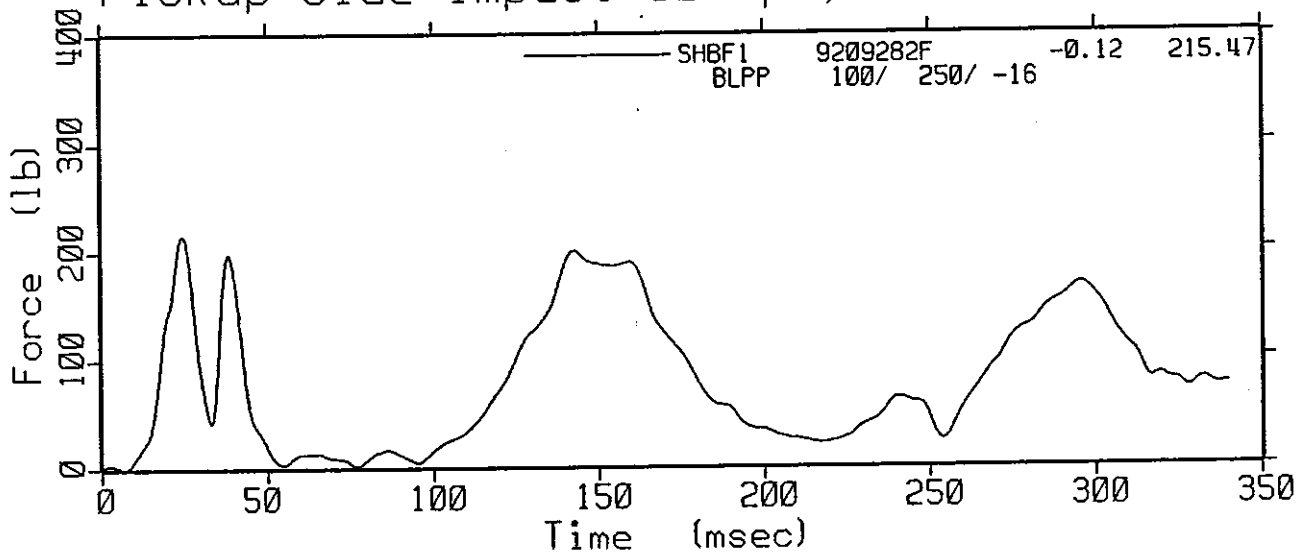


Pickup truck side impact 30 mph driver

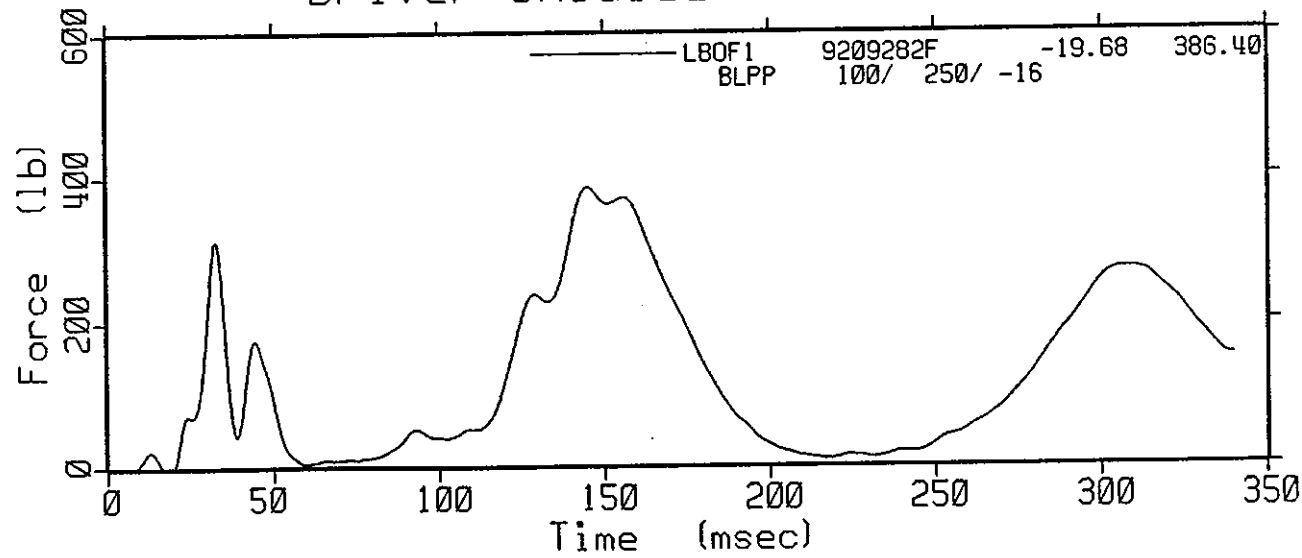
5-NOV-92 12:57



Pickup side impact 30 mph, driver buckle



Driver Shoulder Belt Force



Driver Lap Belt Force

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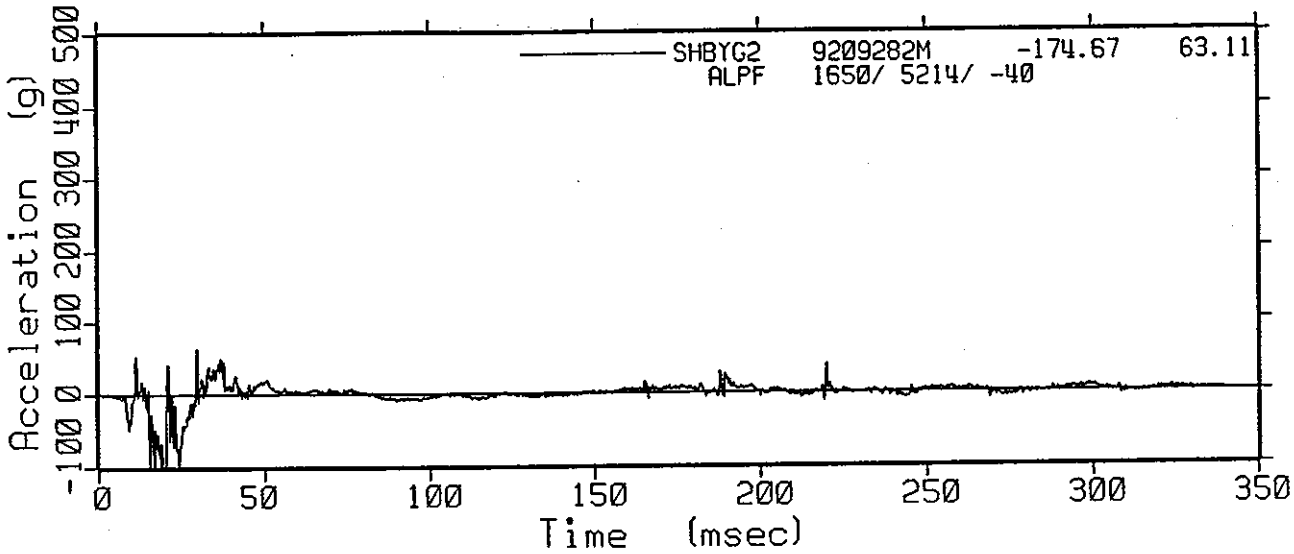
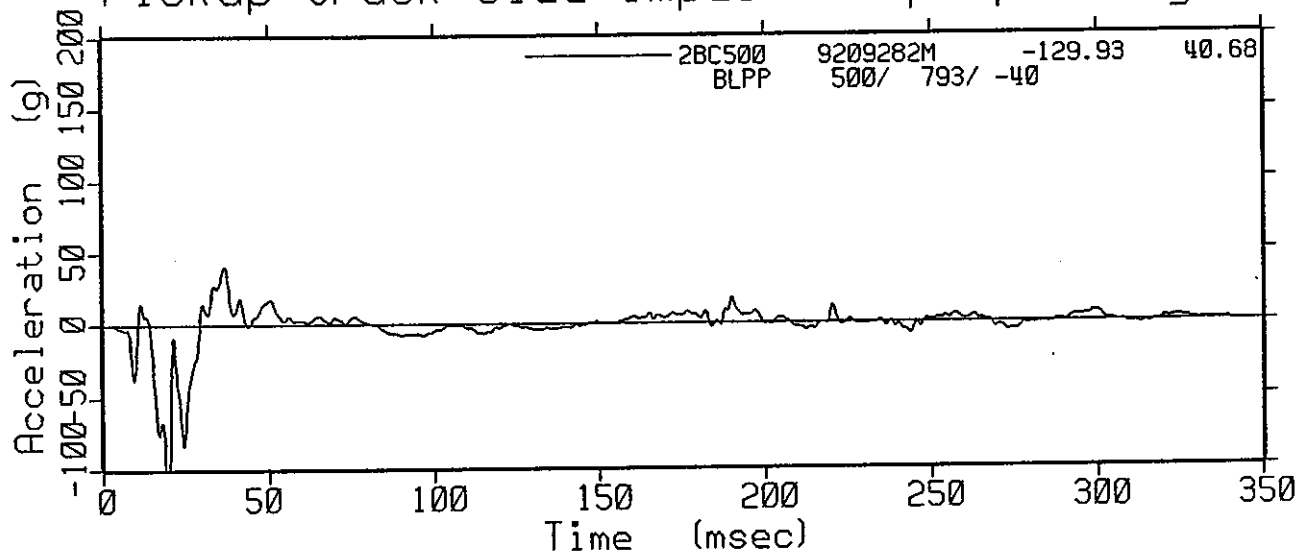
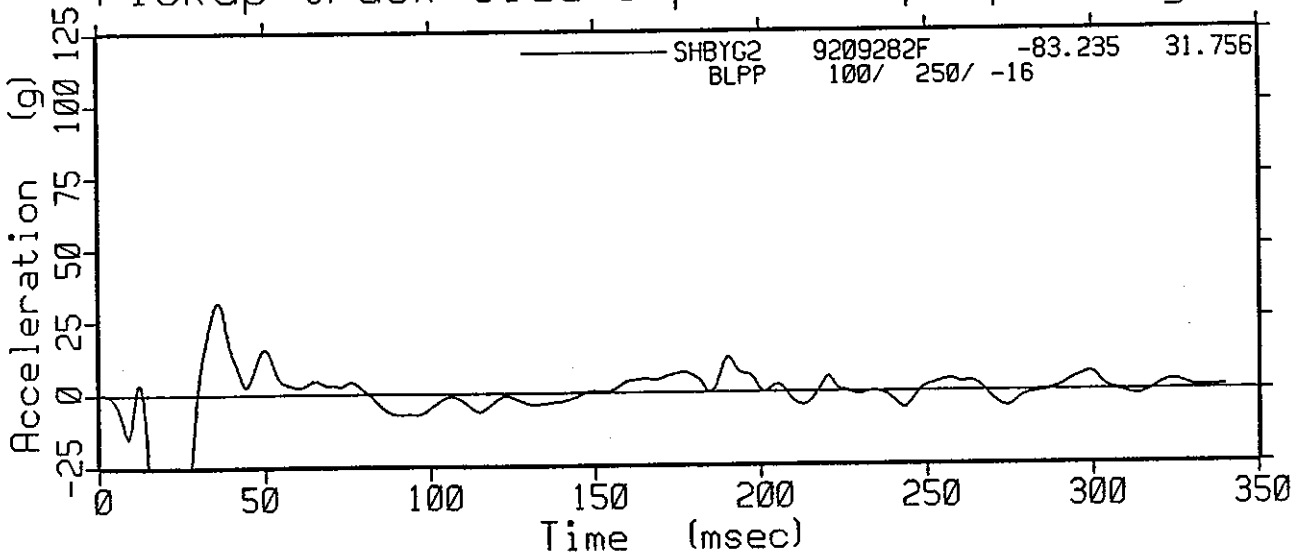


Pickup truck side impact 30mph passenger

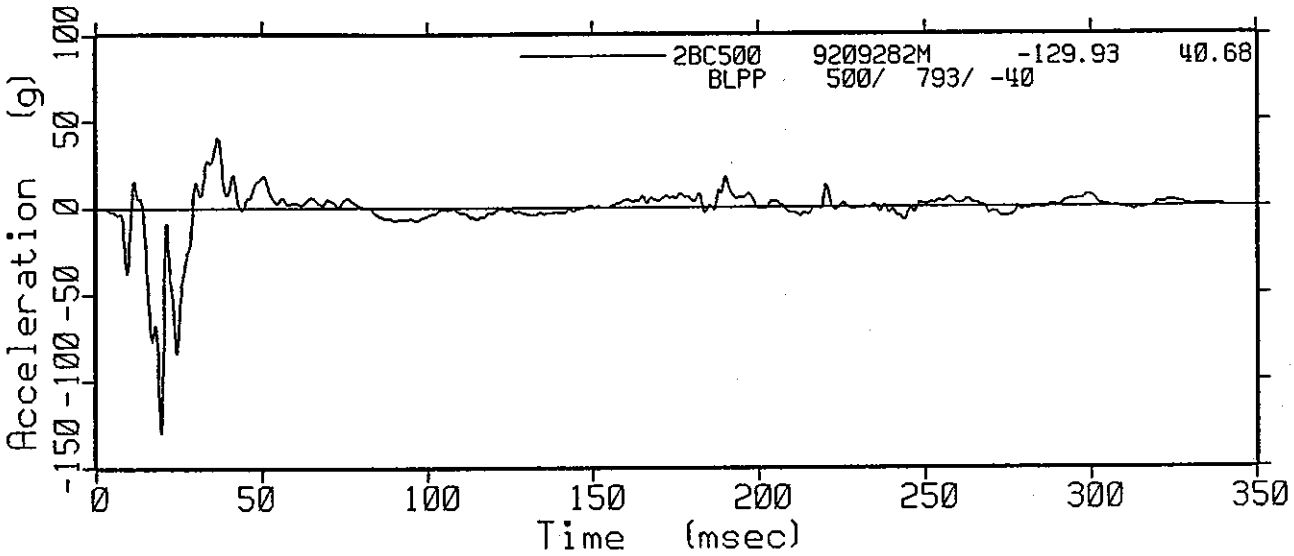


Pickup truck side impact 30mph passenger

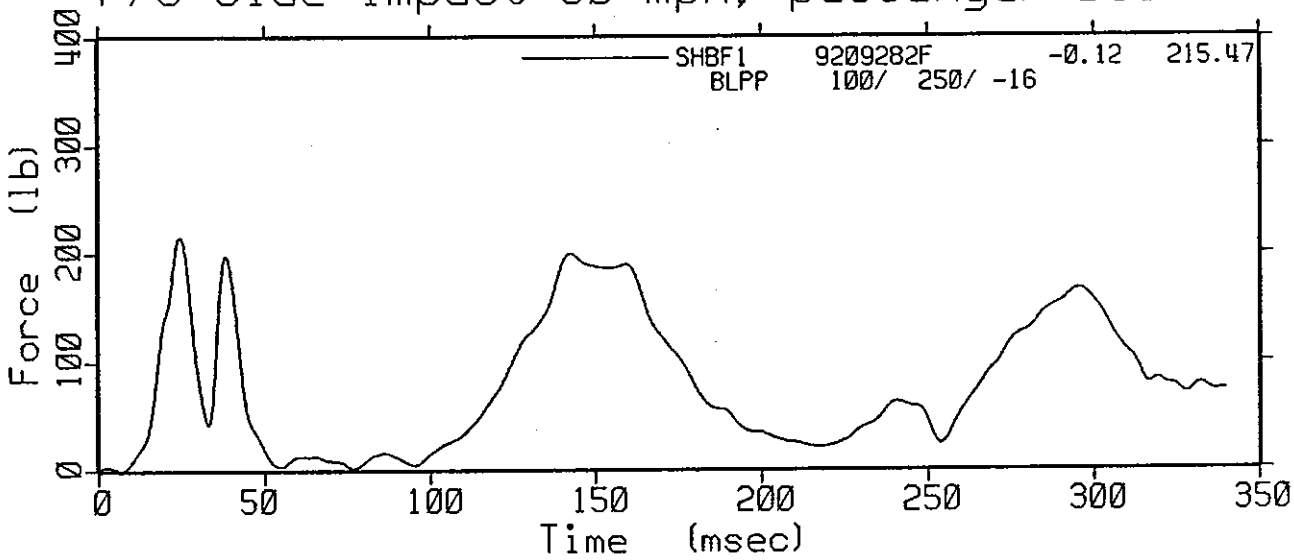


Pickup truck side impact 30mph passenger

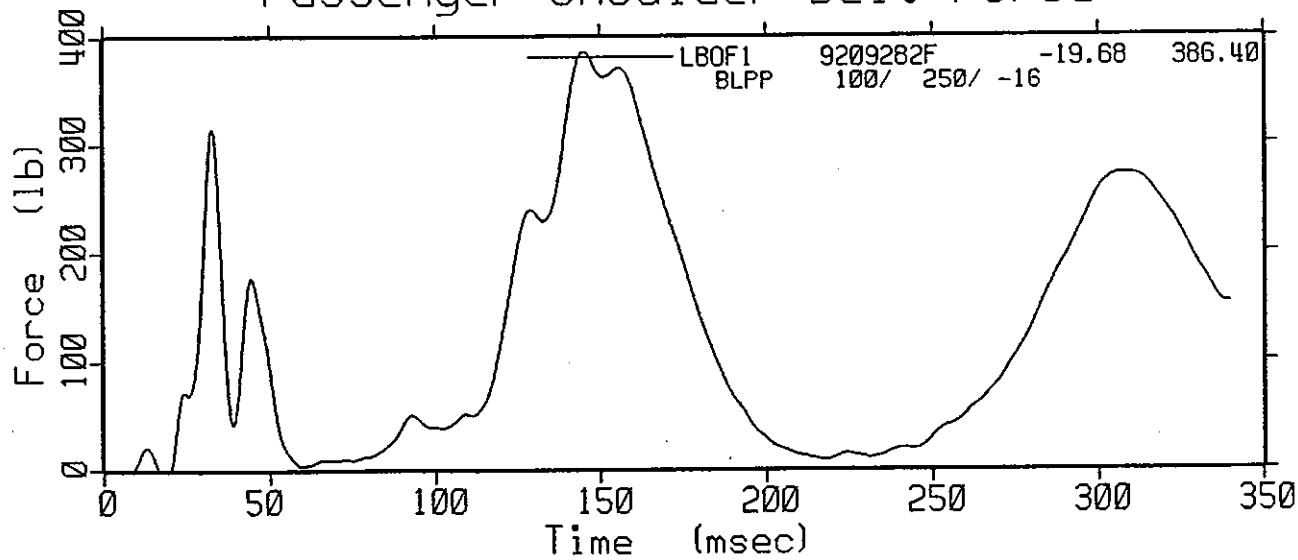
5-NOV-92 12:57



P/U side impact 30 mph, passenger buckle



Passenger Shoulder Belt Force



Passenger Lap Belt Force

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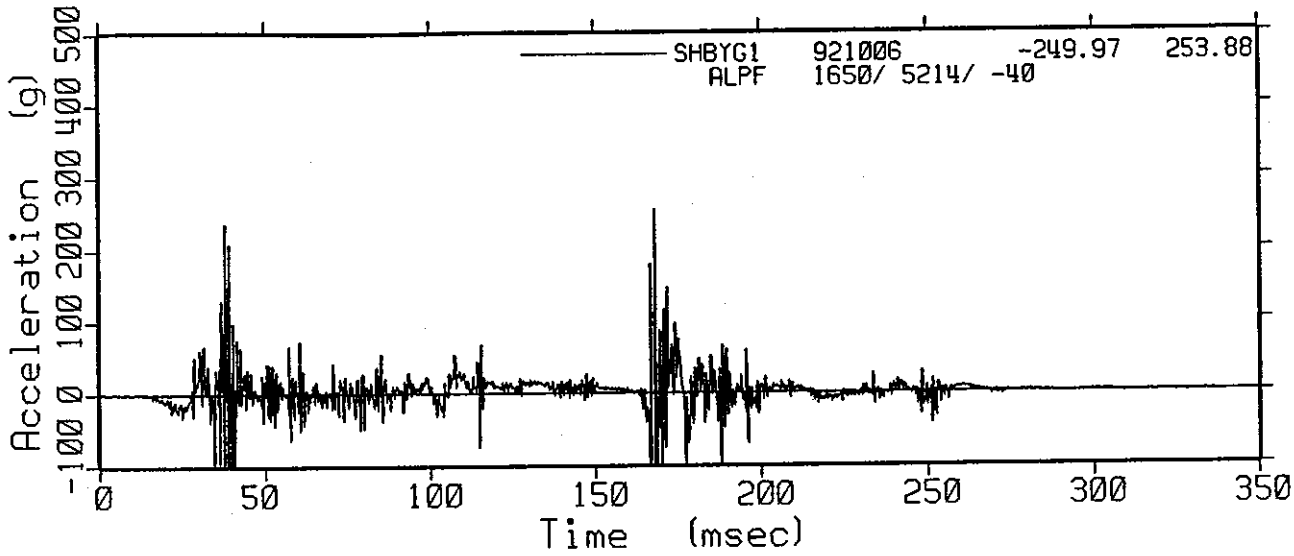
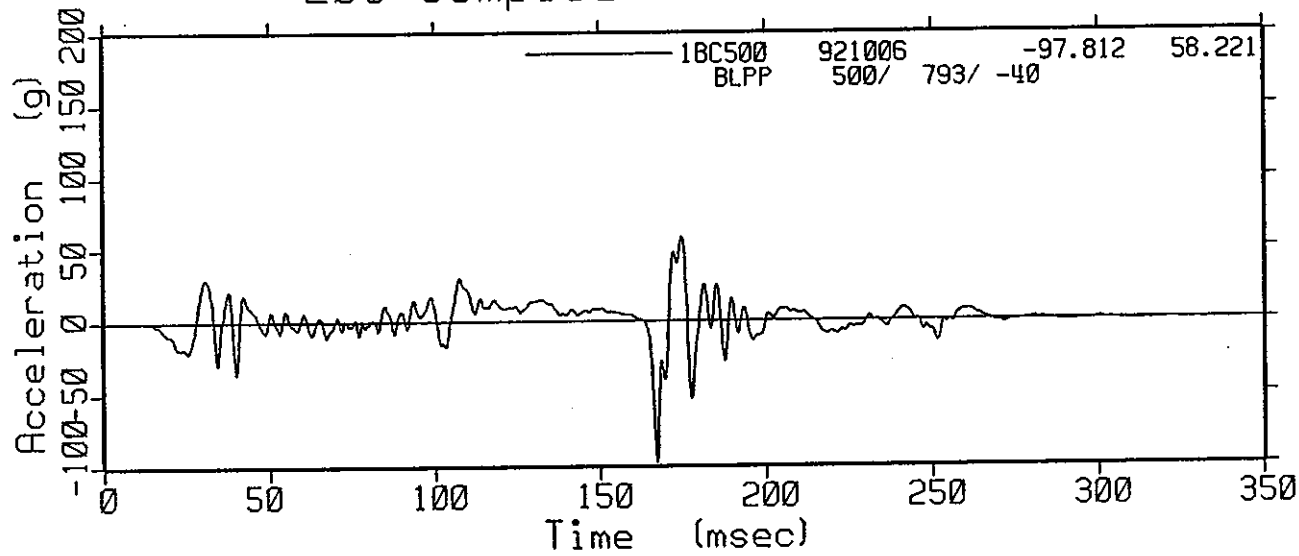


208 Compliance test driver



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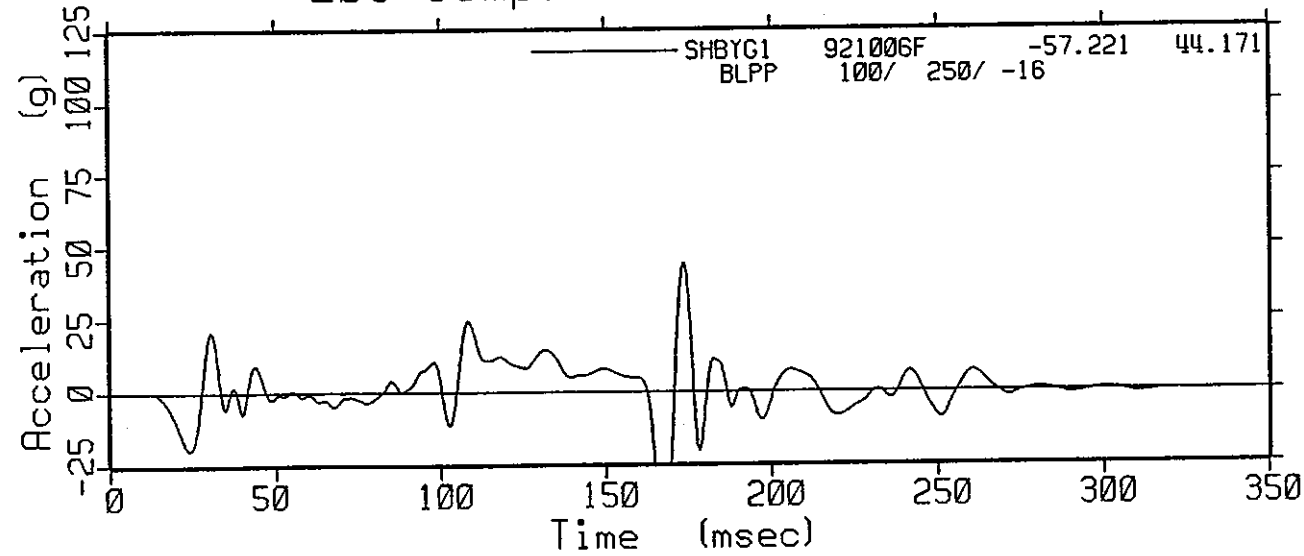

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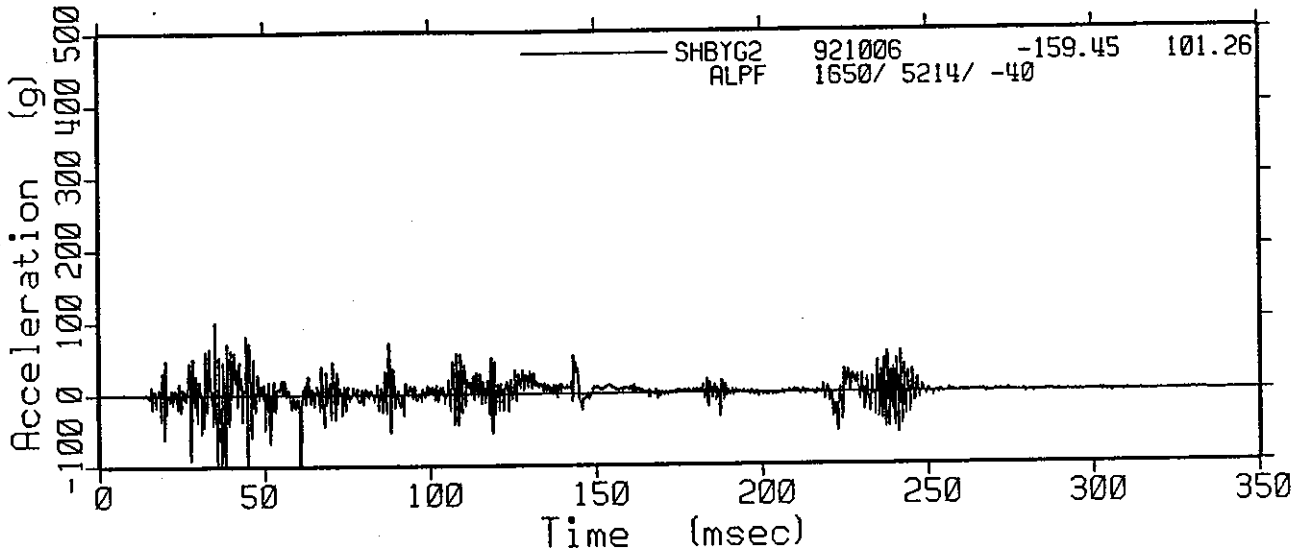
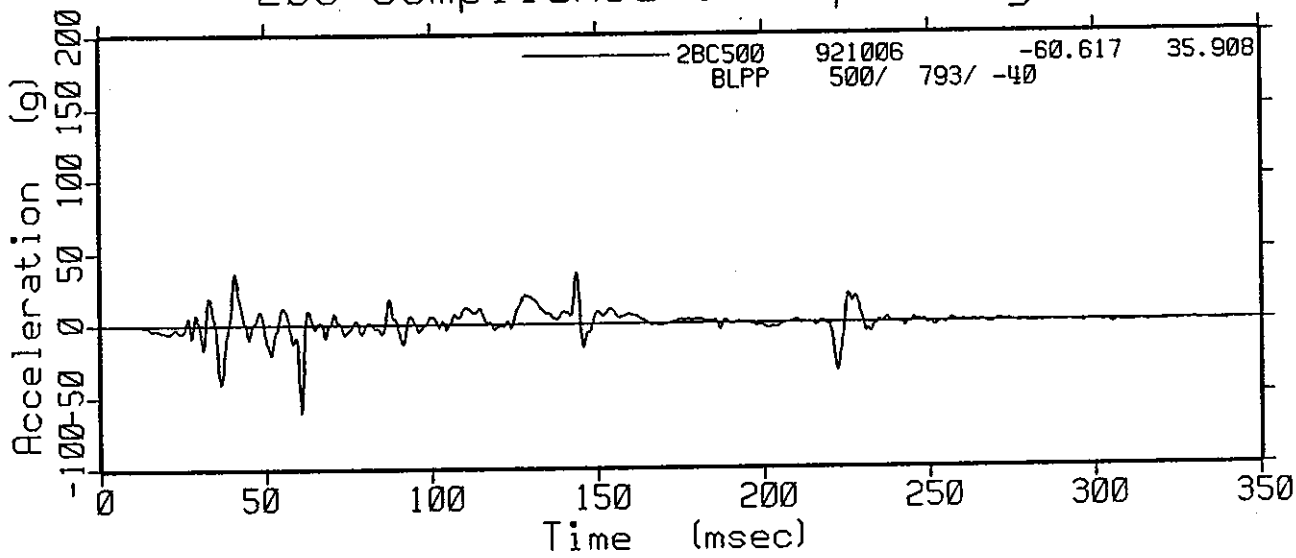


208 Compliance test passenger



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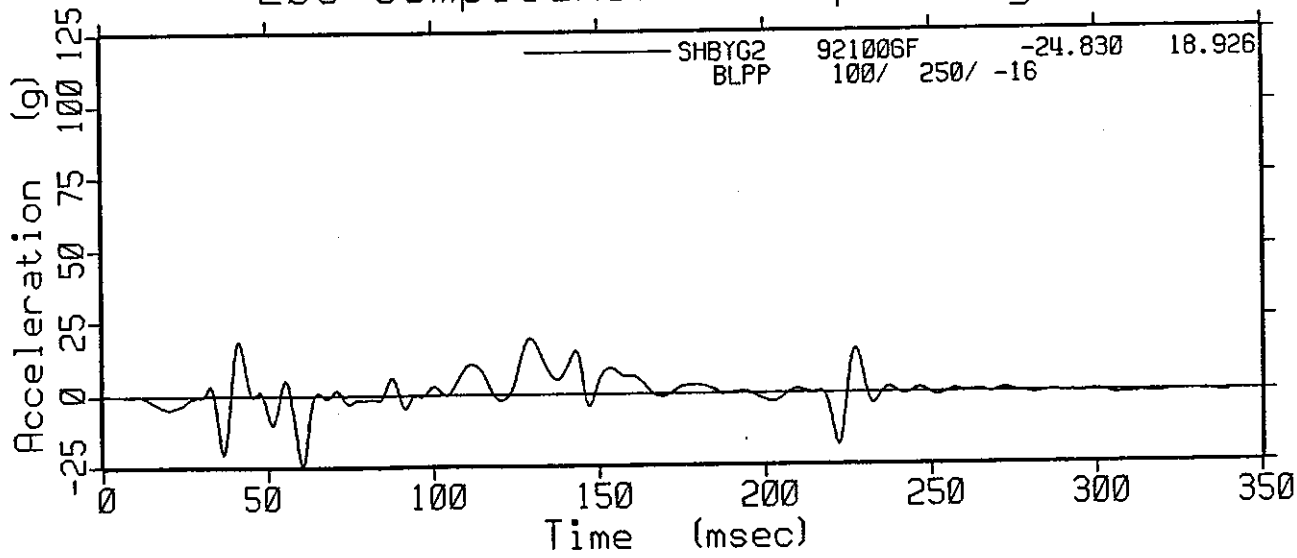
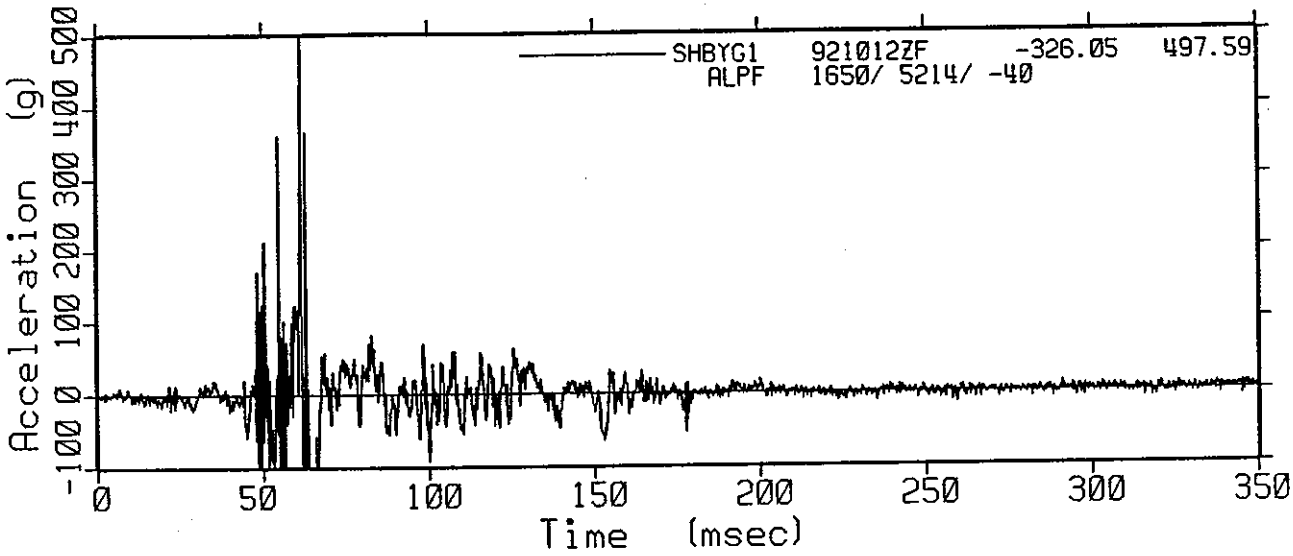
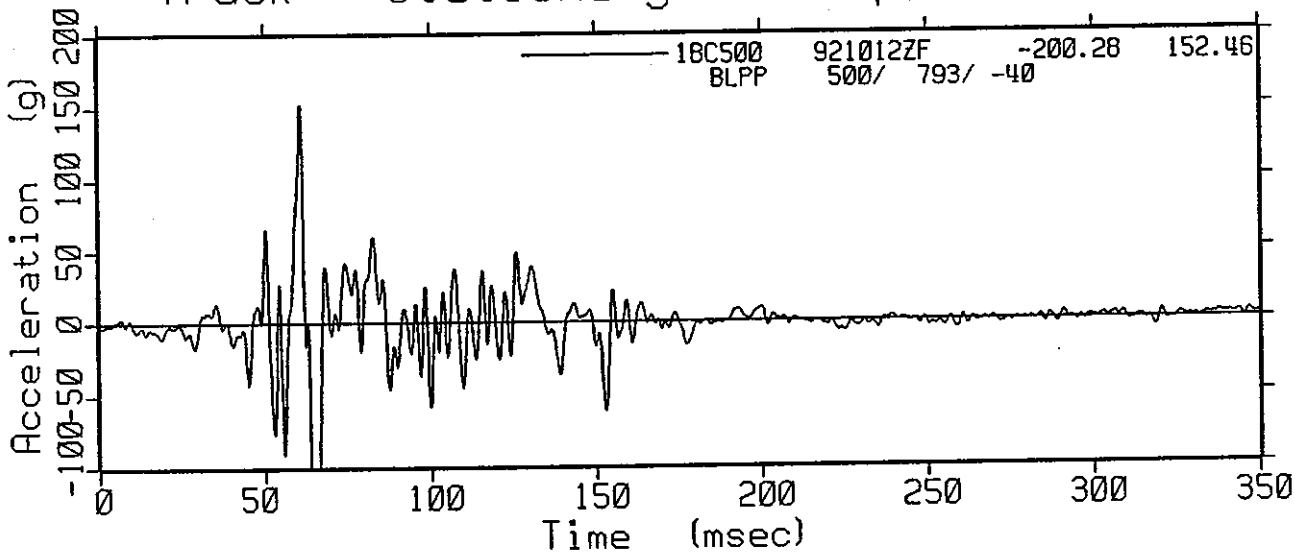


208 Compliance test passenger

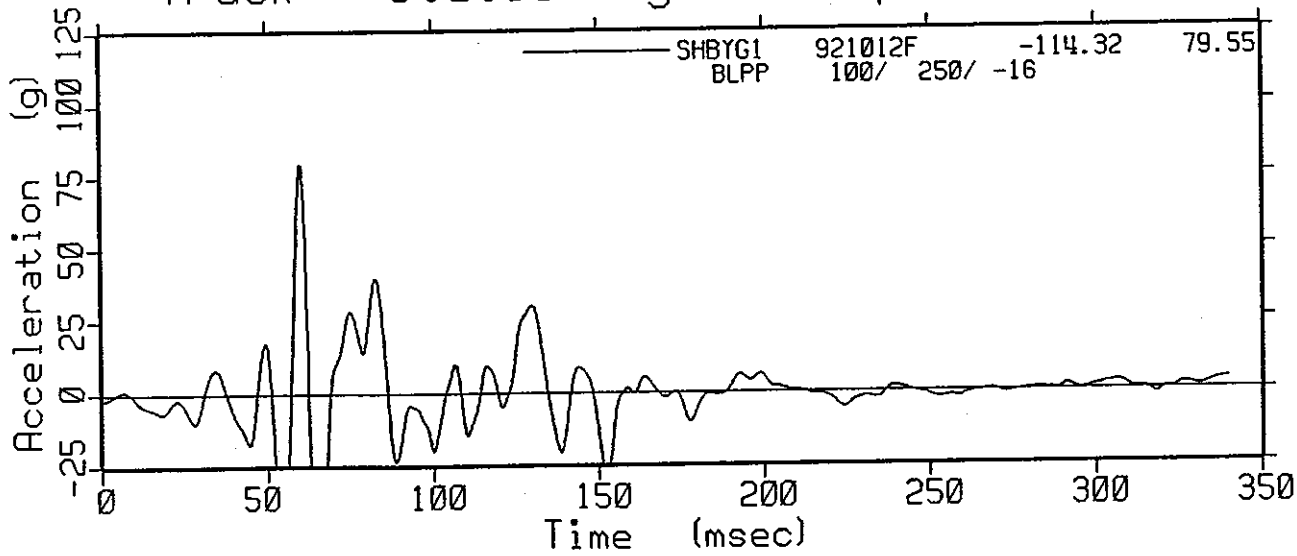
3-NOV-92 15:00



Truck - stationary car impact driver

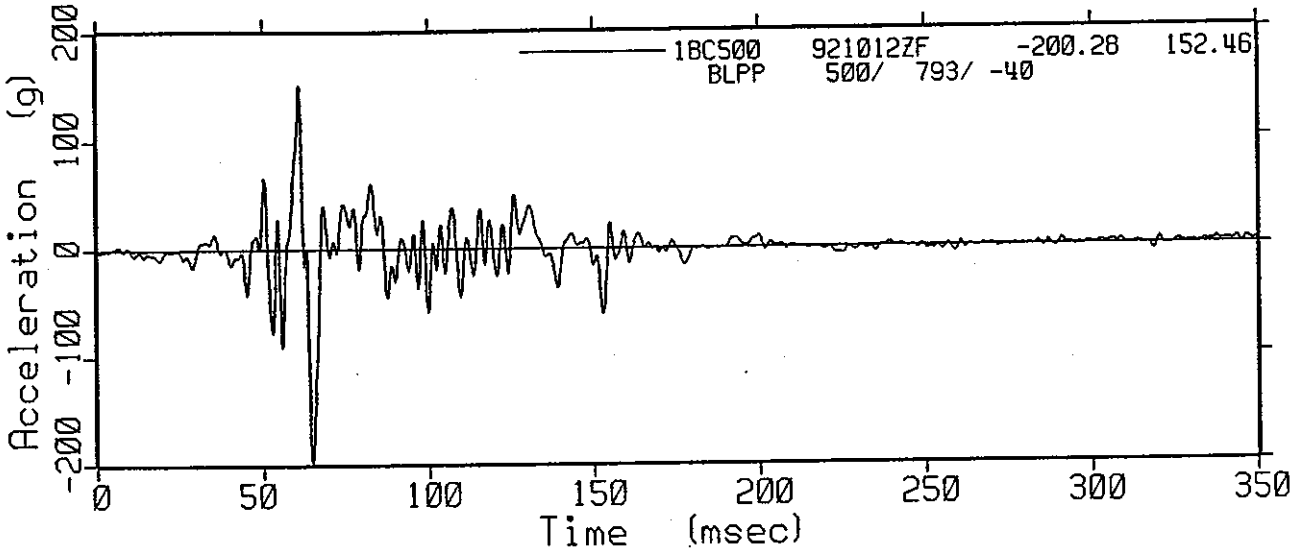


Truck - stationary car impact driver

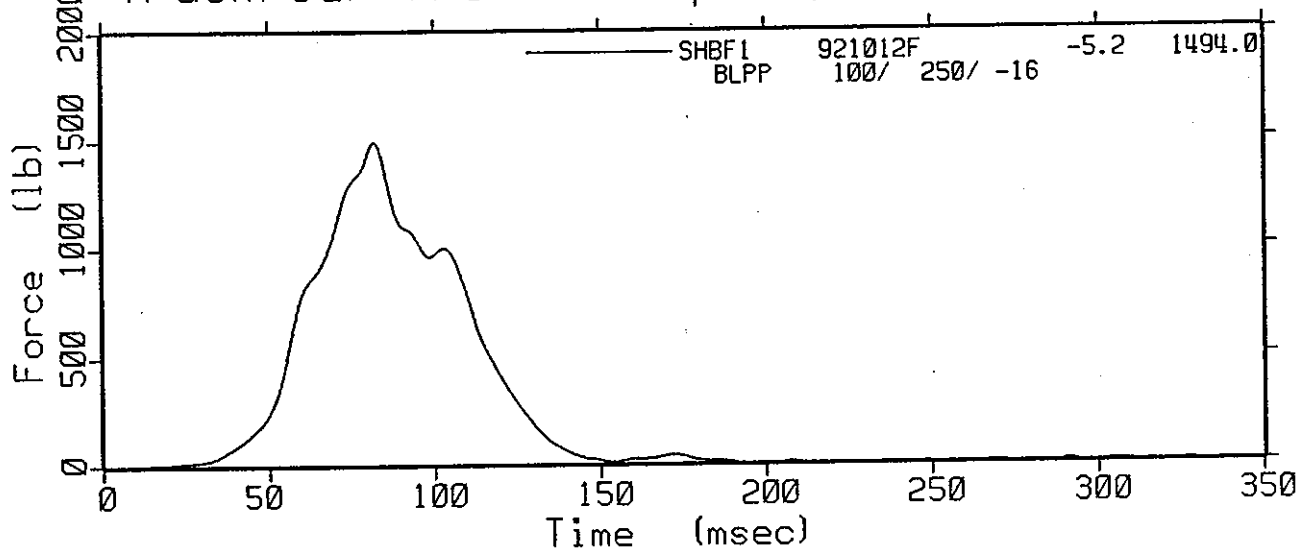


Truck - stationary car impact driver

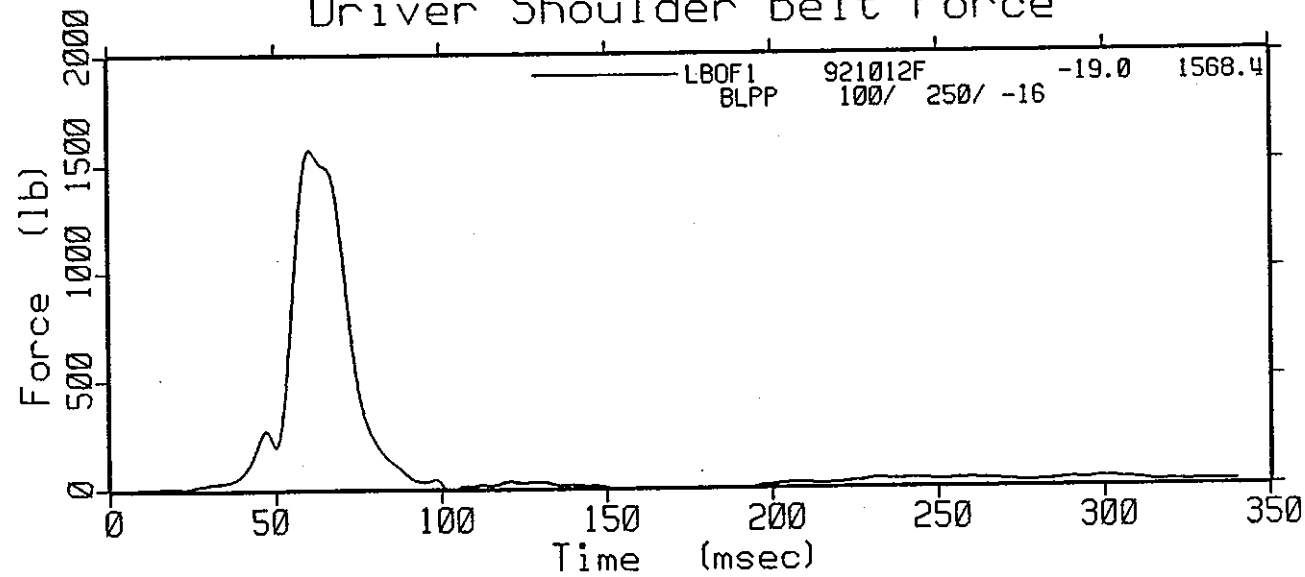
5-NOV-92 12:57



Truck/car frontal impact, driver buckle

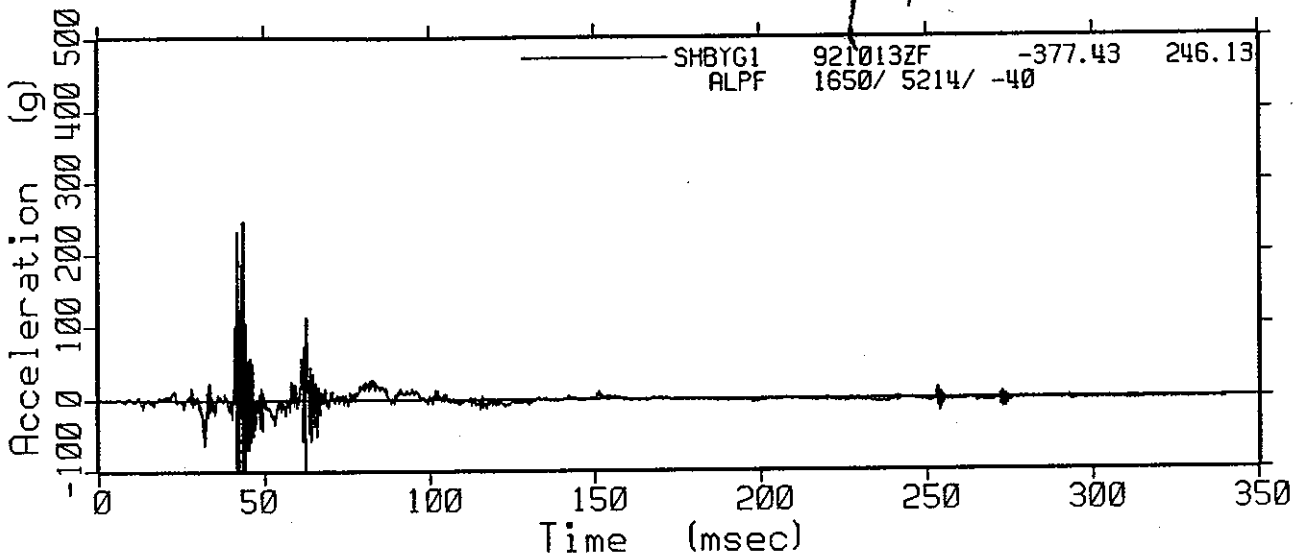


Driver Shoulder Belt Force

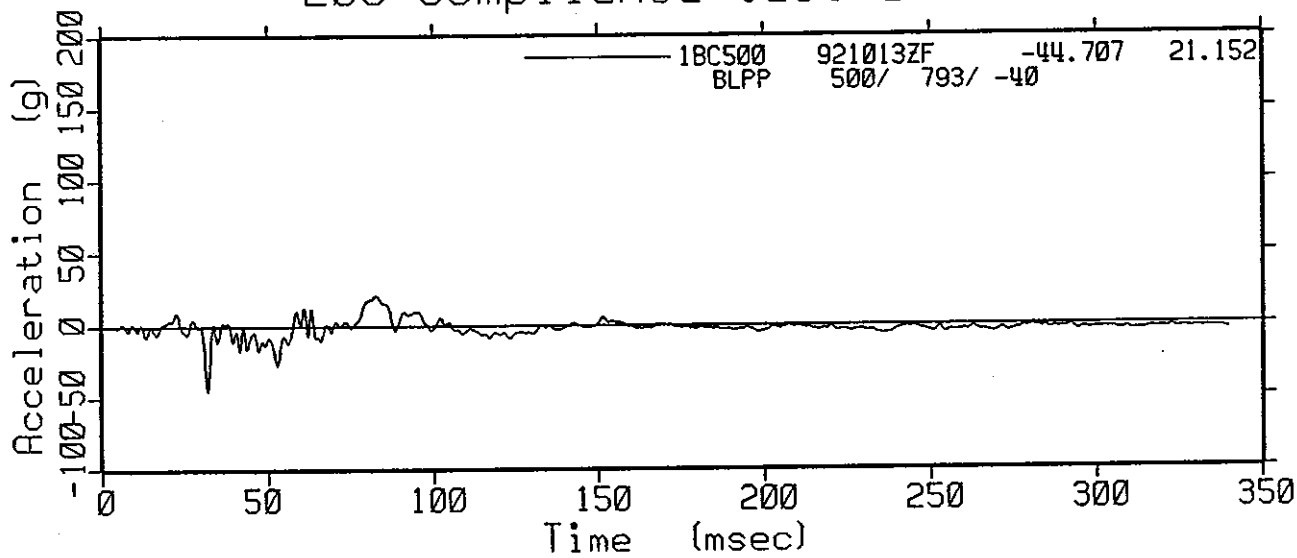


Driver Lap Belt Force

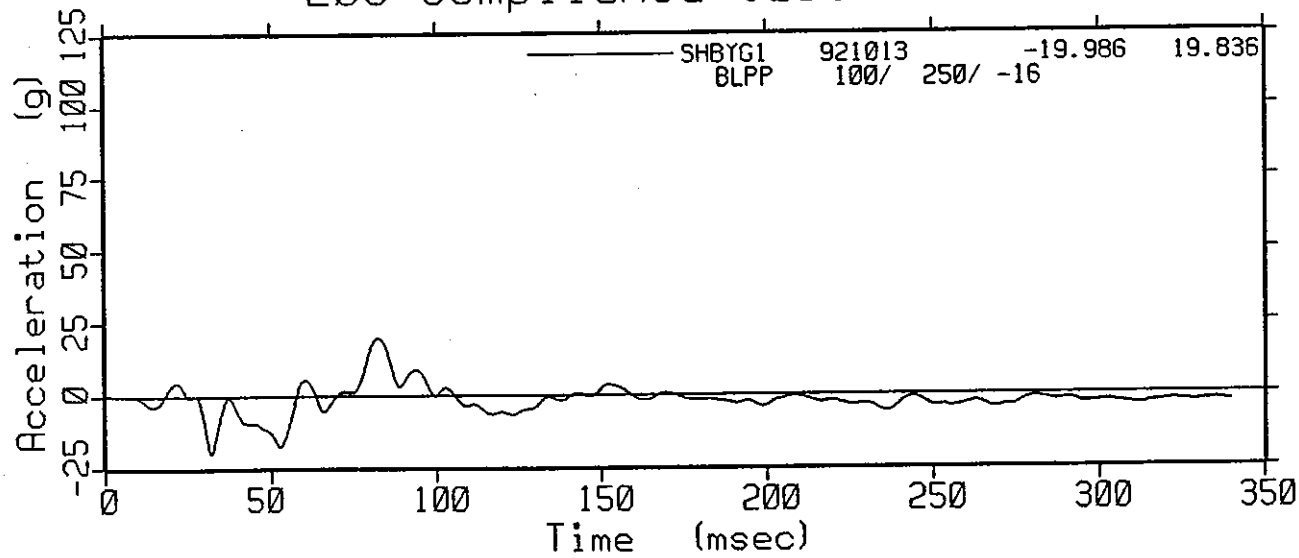
3-NOV-92 15:00



208 Compliance test driver

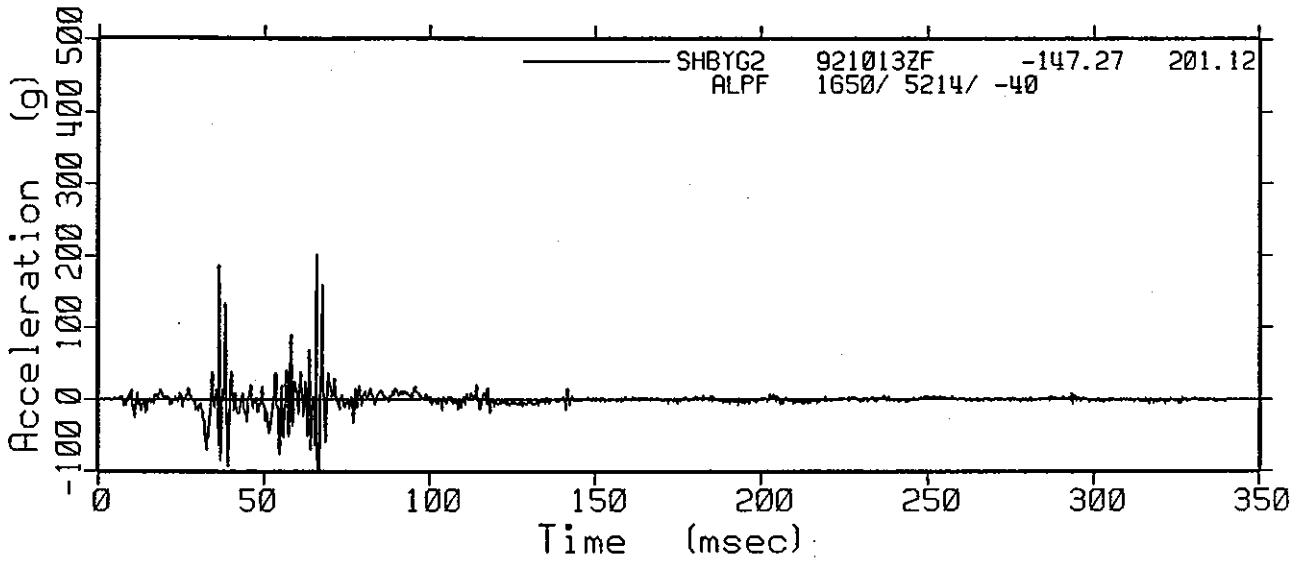


208 Compliance test driver

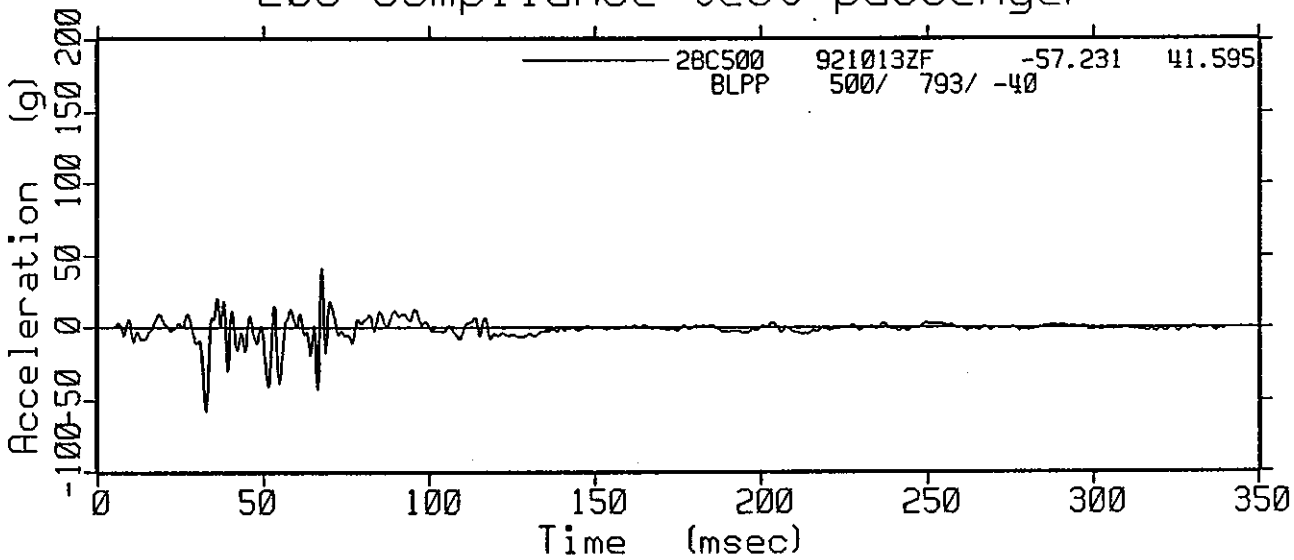


208 Compliance test driver

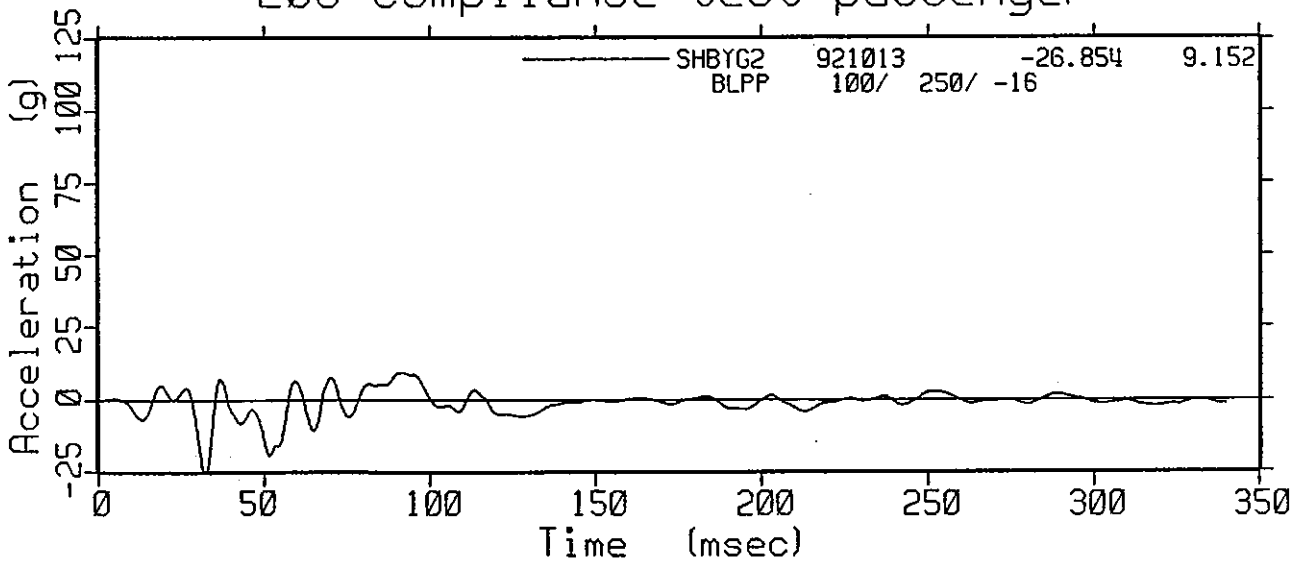
3-NOV-92 15:00



208 Compliance test passenger

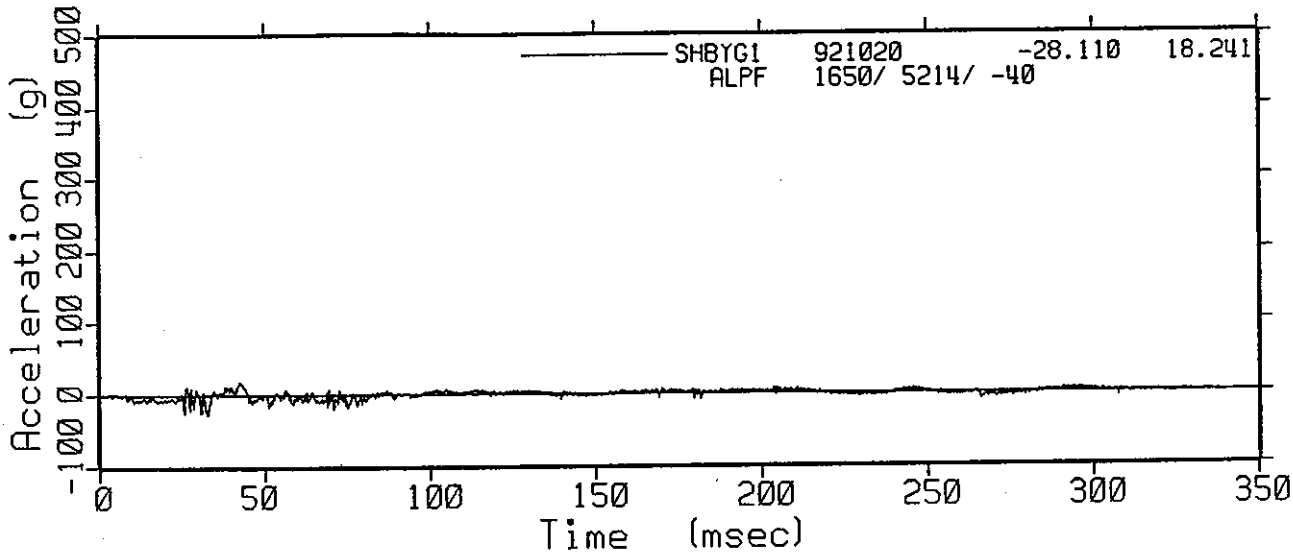


208 Compliance test passenger

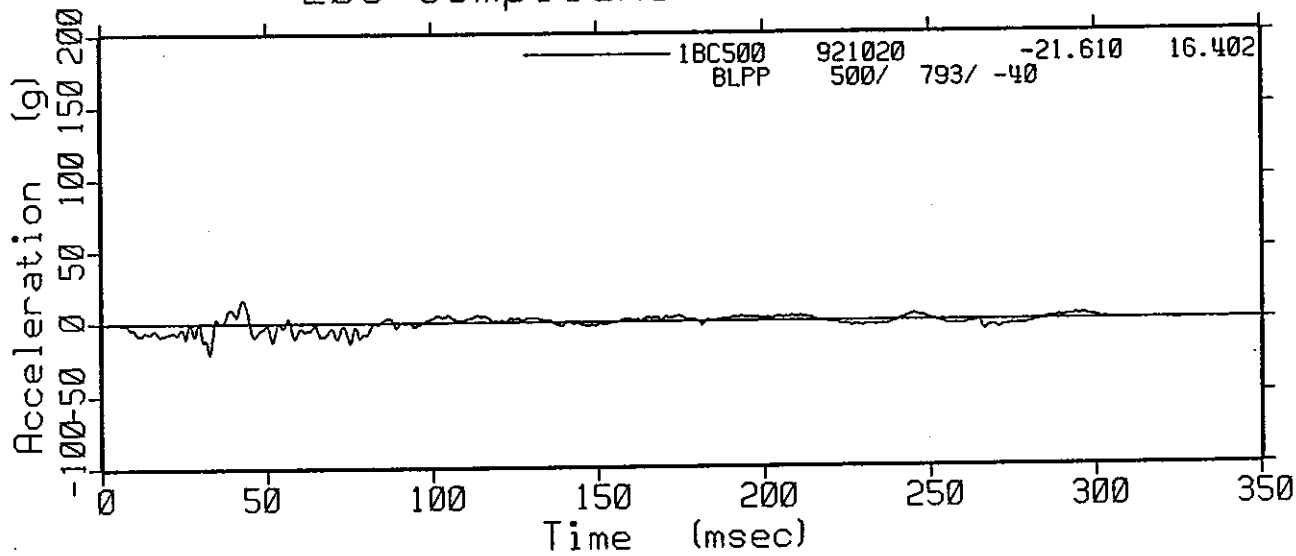


208 Compliance test passenger

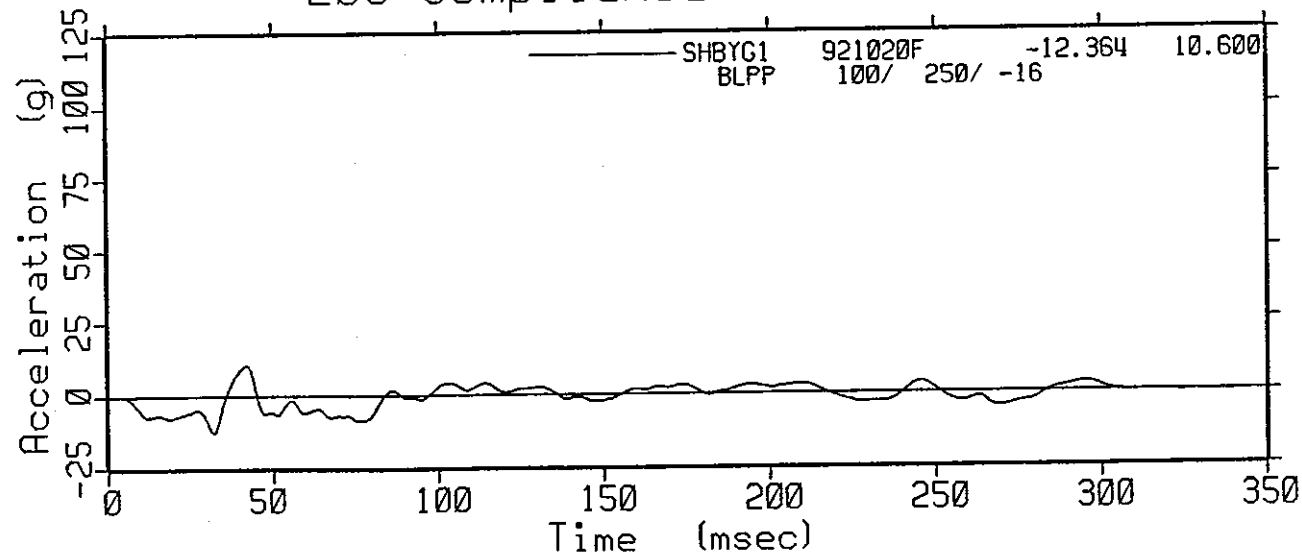
3-NOV-92 15:00



208 Compliance test driver

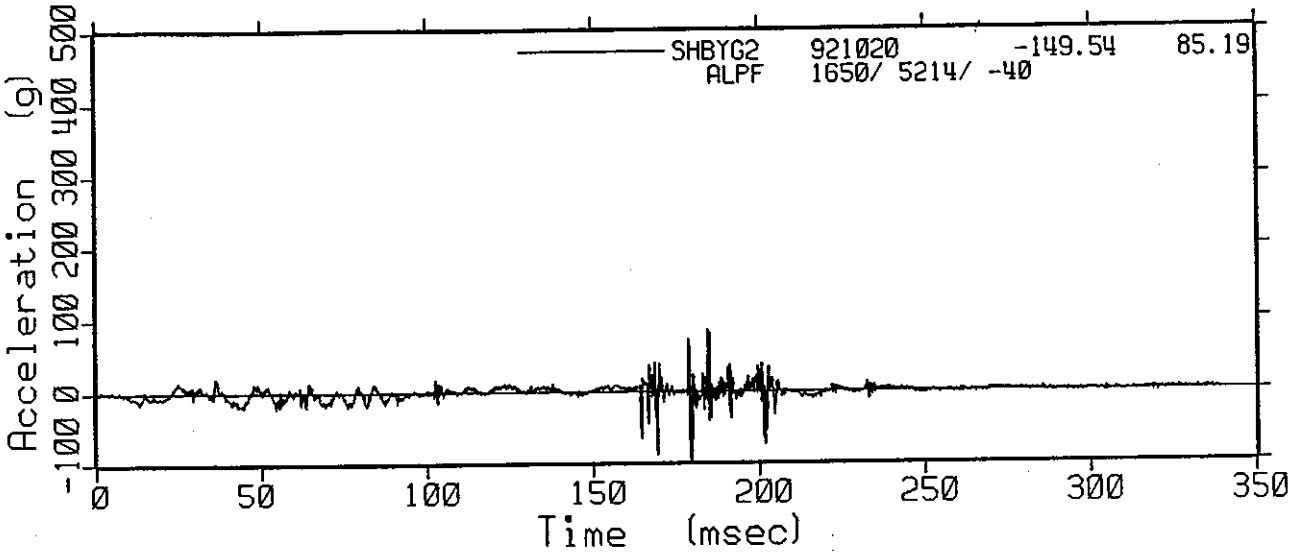


208 Compliance test driver

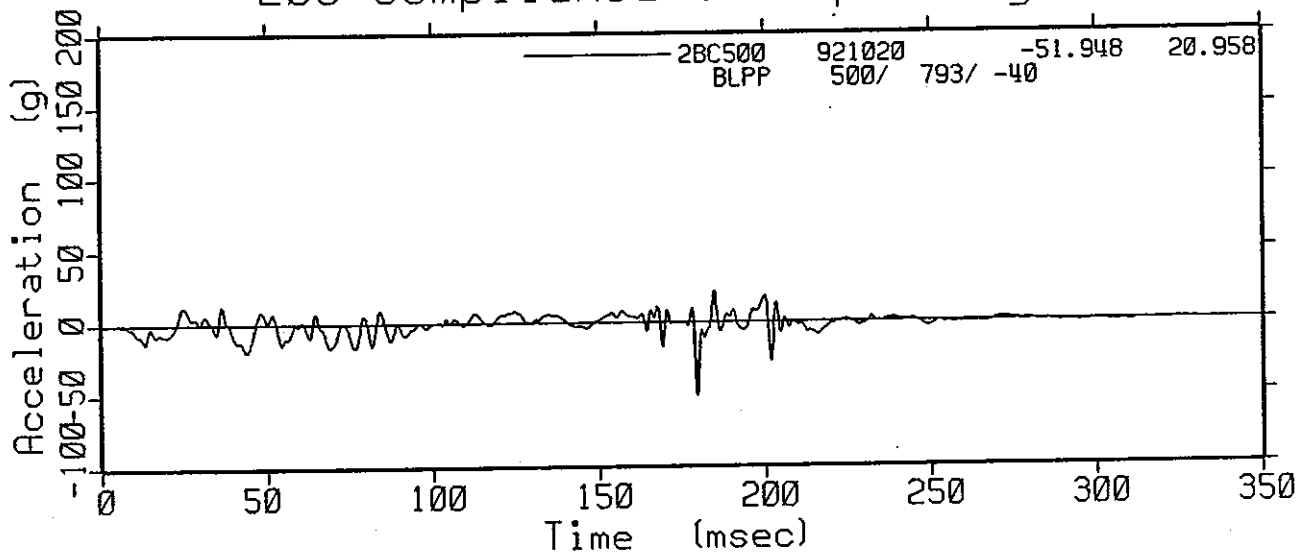


208 Compliance test driver

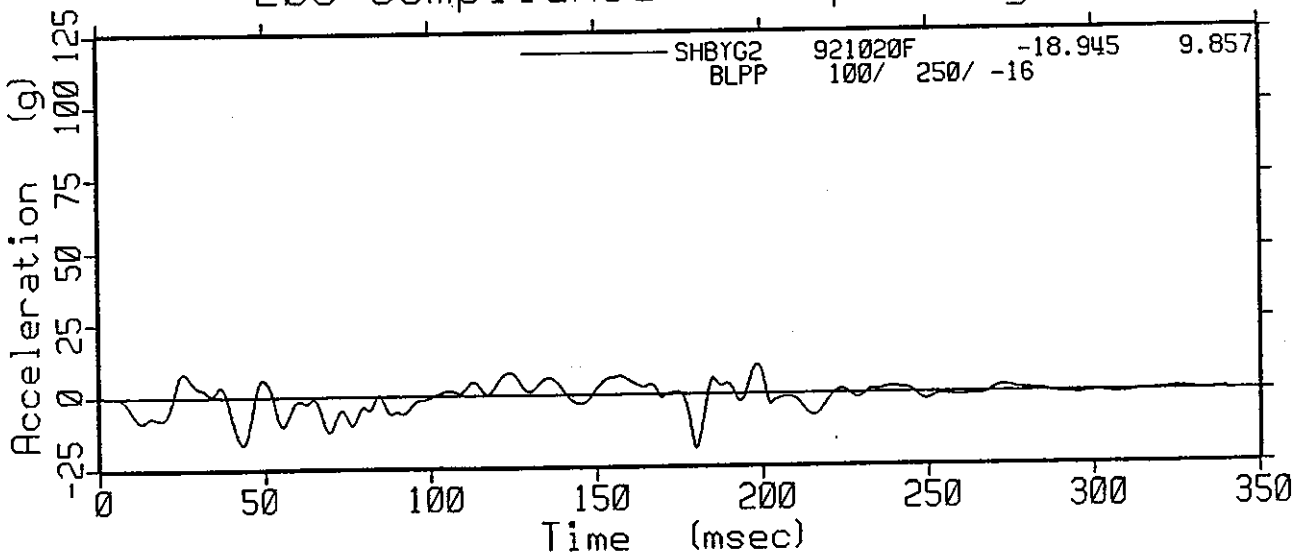
3-NOV-92 15:00



208 Compliance test passenger



208 Compliance test passenger



208 Compliance test passenger

APPENDIX F

Math Model of GM Safety Belt Buckle

Analysis for 0 lbs belt tension

Define the System: spring, mass, omega

```
k=58.6 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=1.224 (*lbf*); correctionfactor0=intercept/m;
```

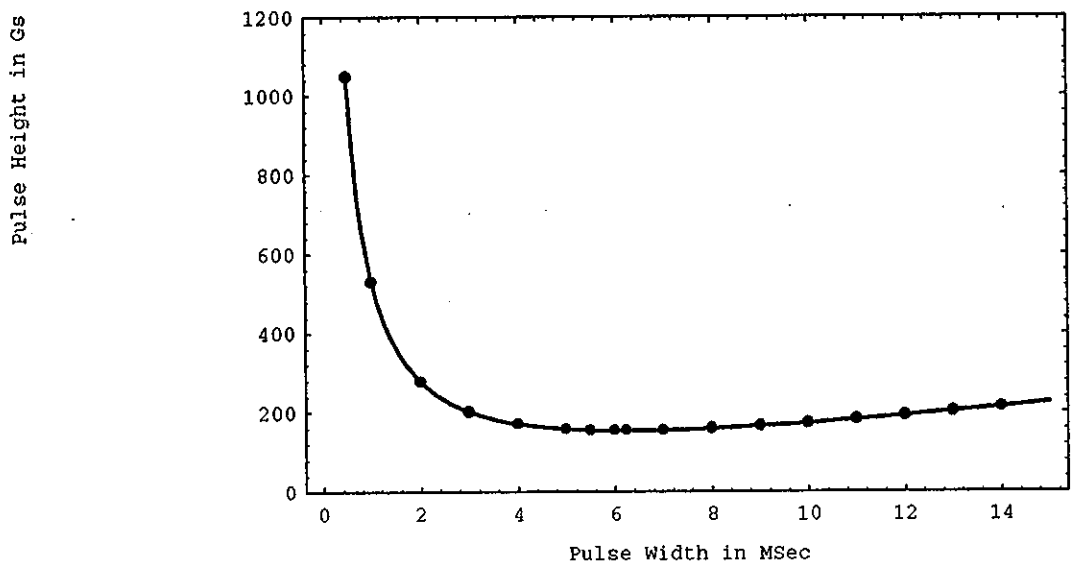
Get (T,G) values for failure (Note: Here, T in msec, G in g's)

```
points0g = {{0.5,1047.5},{1,530.3},{2,278.8},{3,202.27},{4,171.05},{5,158.2},
{5.5,155.4},{6,154.25},{6.2354,154.1},{7,155.25},{8,159.3},{9,165.6},
{10,173.35},{11,182.3},{12,192.2},{13,202.7},{14,213.8}};
```

Find the final curve, corrected for the intercept

$$7.66256 + \frac{15.3129}{x^3} - \frac{62.0231}{x^2} + \frac{605.388}{x} + 19.3086\,x - 0.46768\,x^2 + 0.0144093\,x^3$$

Display an overlay of the points and the fit



Analysis for 50 lbs belt tension

Define the System: spring, mass, omega

```
k=99.6 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=2.98 (*lbf*); correctionfactor50=intercept/m;
```

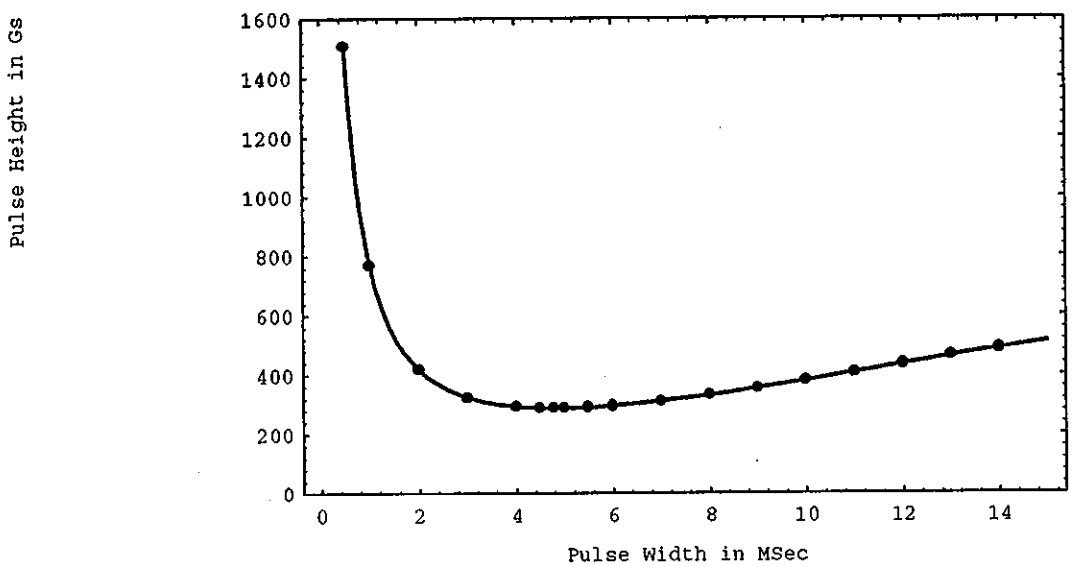
Get (T,G) values for failure (Note: Here, T in msec, G in g's)

```
points50g = {{0.5,1506.5},{1,769.45},{2,419.18},{3,323.2},{4,293.12},{4.5,288.7},
{4.78282,288.13},{5,288.45},{5.5,291.2},{6,296.2},{7,311.25},{8,331.1},
{9,354.25},{10,379.8},{11,406.9},{12,434.6},{13,461.8},{14,485.75}};
```

Find the final curve, corrected for the intercept

$$168.768 - \frac{30.2233}{x^3} + \frac{106.419}{x^2} + \frac{639.178}{x} + 17.4151\,x + 1.65562\,x^2 - 0.0593838\,x^3$$

Display an overlay of the points and the fit



Analysis for 200 lbs belt tension

- Define the System: spring, mass, omega

```
k=189.1 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=6.85 (*lbf*); correctionfactor200=intercept/m;
```

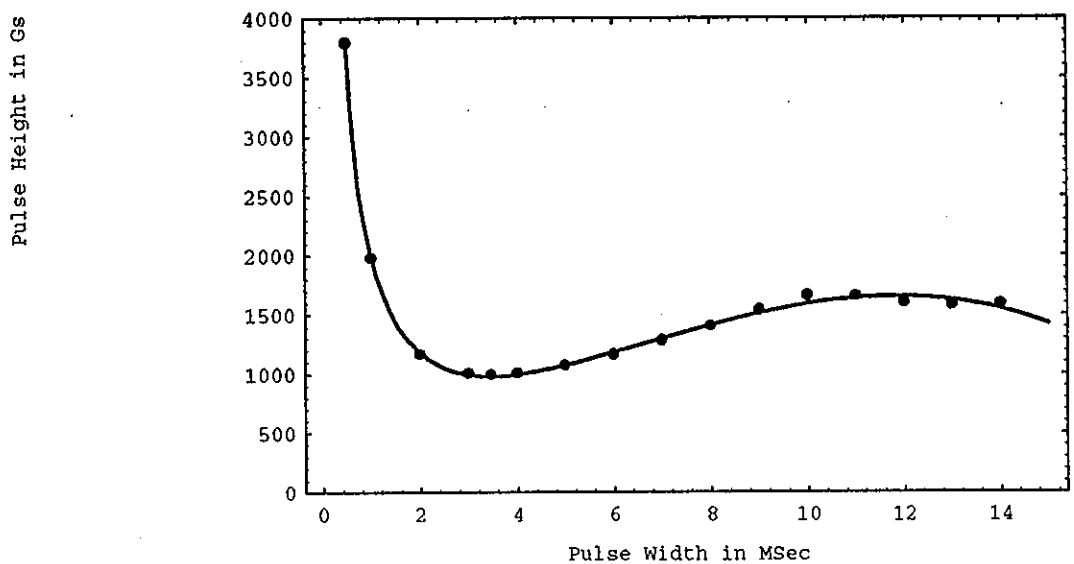
- Get (T,G) values for failure (Note: Here, T in msec, G in g's)

```
points200g = {{.5,3798},{1,1977.5},{2,1166},{3,1006.1},
{3.47111,994.6},{4,1005.5},{5,1067.8},{6,1163.5},{7,1279},{8,1406.5},
{9,1538.5},{10,1660.6},{11,1653.5},{12,1601},{13,1584.1},{14,1591.85}};
```

- Find the final curve, corrected for the intercept

$$-399.029 + \frac{349.297}{x^3} - \frac{1305.79}{x^2} + \frac{3409.76}{x} + 224.922\,x + 4.67509\,x^2 - 0.744619\,x^3$$

- Display an overlay of the points and the fit



Analysis for 500 lbs belt tension - Case 1

- Define the System: spring, mass, omega

```
k=389.763 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=7.97 (*lbf*); correctionfactor5001=intercept/m;
```

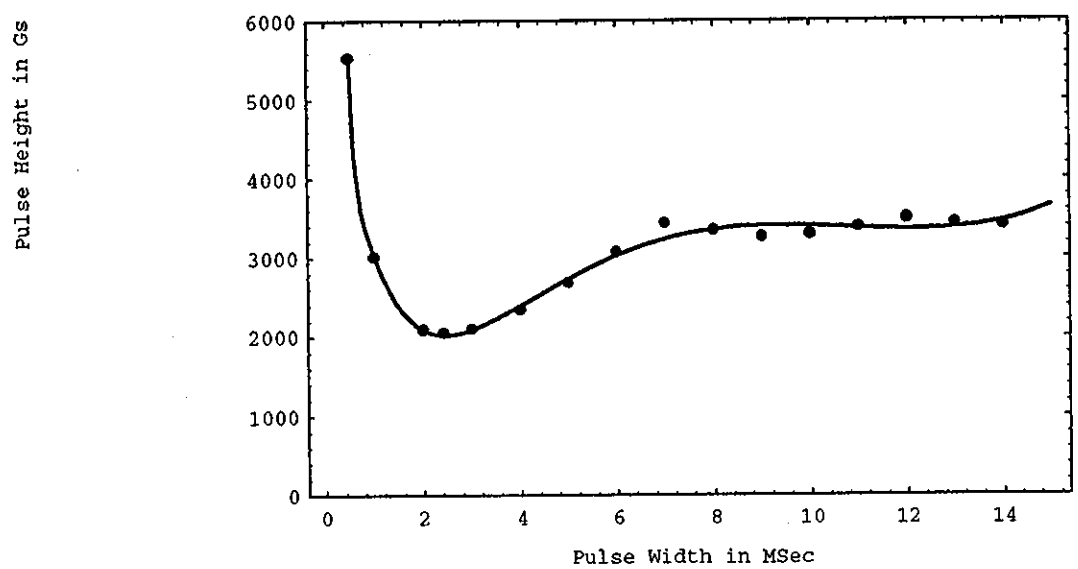
- Get (T,G) values for failure (Note: Here, T in msec, G in g's)

```
points5001g = {{.5,5531.5},{1,3007.5},{2,2090},{2.41776,2050},
{3,2102},{4,2342.5},{5,2682},{6,3066.5},{7,3434},{8,3345.5},
{9,3265.5},{10,3295.5},{11,3385.5},{12,3490.5},{13,3429},{14,3397}};
```

- Find the final curve, corrected for the intercept

$$-7263.48 + \frac{2349.38}{x^3} - \frac{9487.27}{x^2} + \frac{15583.}{x} + 2379.59\,x - 201.105\,x^2 + 5.87538\,x^3$$

- Display an overlay of the points and the fit



Analysis for 500 lbs belt tension - Case 2

- Define the System: spring, mass, omega

```
k=304.924 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=12.676 (*lbf*); correctionfactor5002=intercept/m;
```

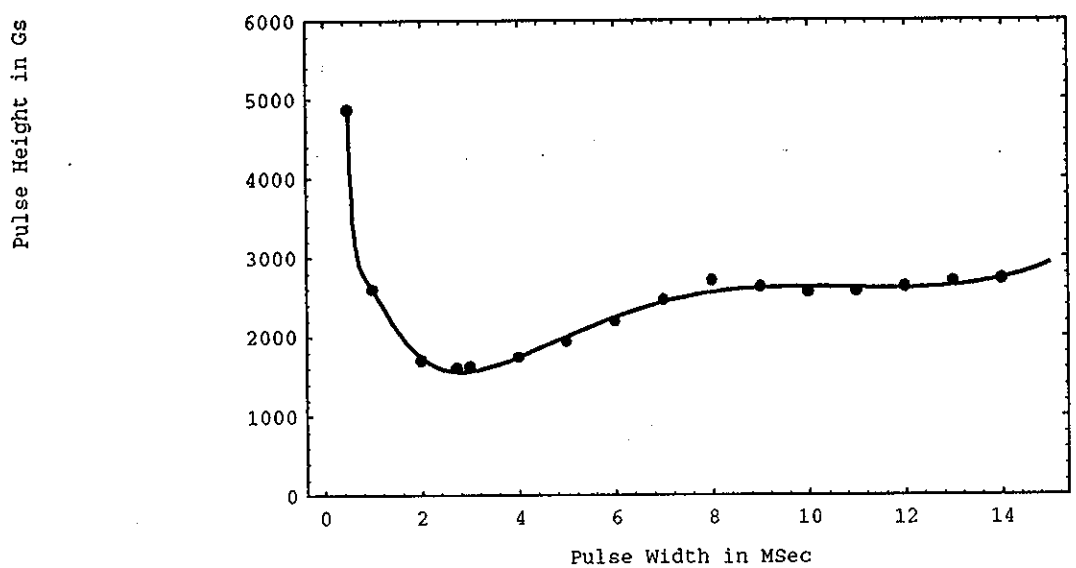
- Get (T,G) values for failure (Note: Here, T in msec, G in g's)

```
points5002g = {{.5,4863},{1,2596},{2,1690},{2.73349,1604},
{3,1611.5},{4,1732.5},{5,1938.5},{6,2188.5},{7,2457.5},{8,2704},
{9,2622.2},{10,2557.5},{11,2566},{12,2618},{13,2691.5},{14,2718}};
```

- Find the final curve, corrected for the intercept

$$-8403.79 + \frac{3392.16}{x^3} - \frac{13223.4}{x^2} + \frac{19232.2}{x} + 2349.85\,x - 192.312\,x^2 + 5.53697\,x^3$$

- Display an overlay of the points and the fit



Analysis for 500 lbs belt tension - Case 3

- Define the System: spring, mass, omega

```
k=253.57 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=20.042 (*lbf*); correctionfactor5003 = intercept/m;
```

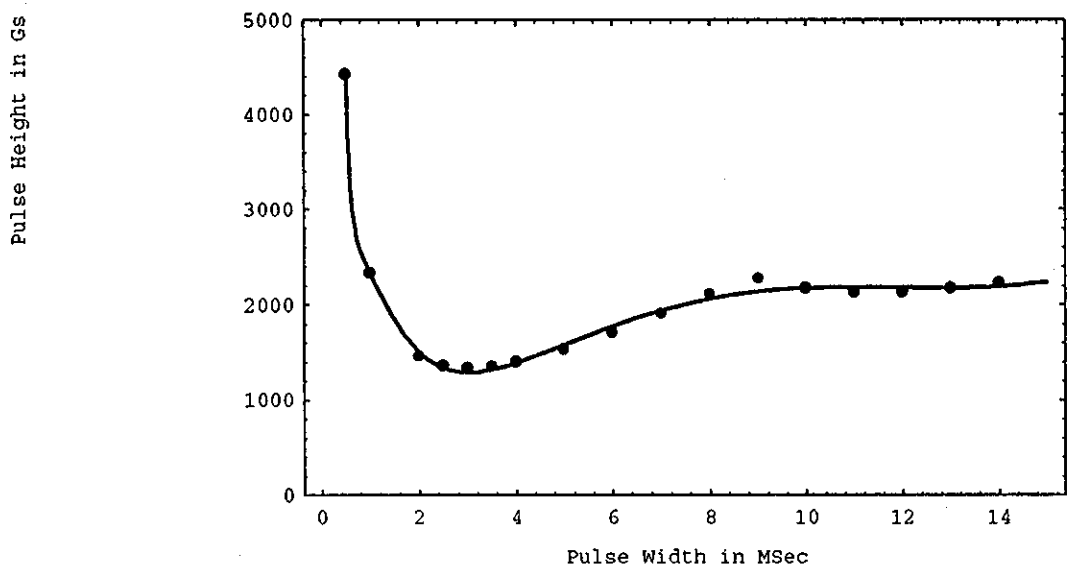
- Get (T,G) values for failure (Note: Here, T in msec, G in g's)

```
points5003g = {{.5,4418.5},{1,2332.7},{2,1455},{2.5,1357.6},{2.99754,1333.7},
{3.5,1351.2},{4,1394.6},{5,1530.5},{6,1706.5},{7,1905},{8,2108.75},
{9,2274},{10,2170},{11,2126.4},{12,2132.2},{13,2169},{14,2223.2}};
```

- Find the final curve, corrected for the intercept

$$-5463.91 + \frac{2555.26}{x^3} - \frac{9863.81}{x^2} + \frac{14510.7}{x} + 1605.75\,x - 120.416\,x^2 + 3.16605\,x^3$$

- Display an overlay of the points and the fit



Analysis for 2000 lbs belt tension

- Define the System: spring, mass, omega

```
k=1033.89 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=46.5996 (*lbf*); correctionfactor2000 = intercept/m;
```

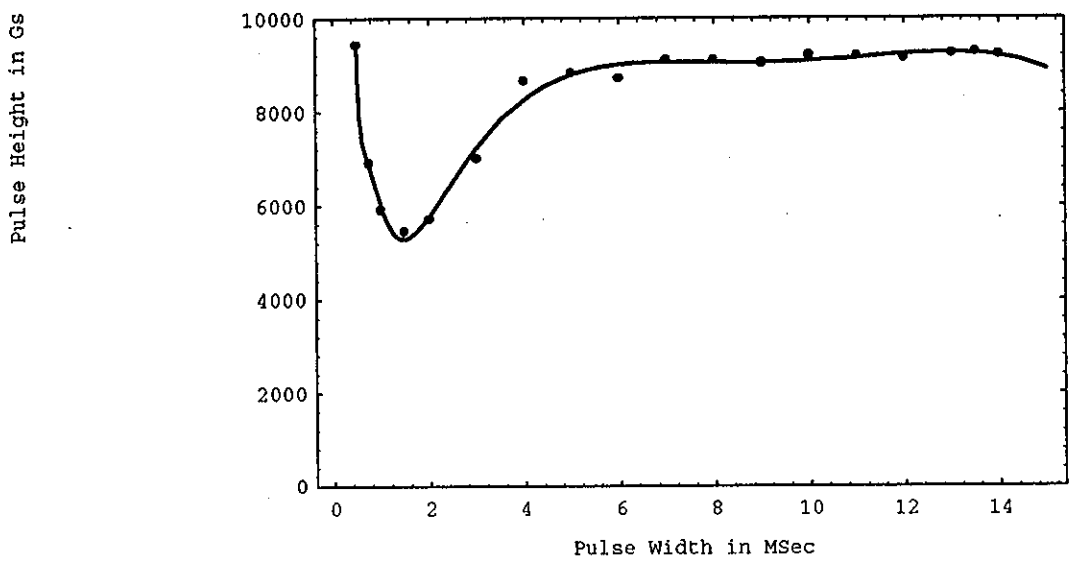
- Get (T,G) values for failure (Note: Here, T in msec, G in g's)

```
points2000g = {{.5,9433.5},{0.75,6906.5},{1,5909},{1.48449,5438},{2,5703.5},
{3,7003},{4,8660},{5,8819},{6,8706.5},{7,9097},{8,9091.5},
{9,9022},{10,9195},{11,9173},{12,9132.5},{13,9230.5},{13.5,9260},{14,9208.5}};
```

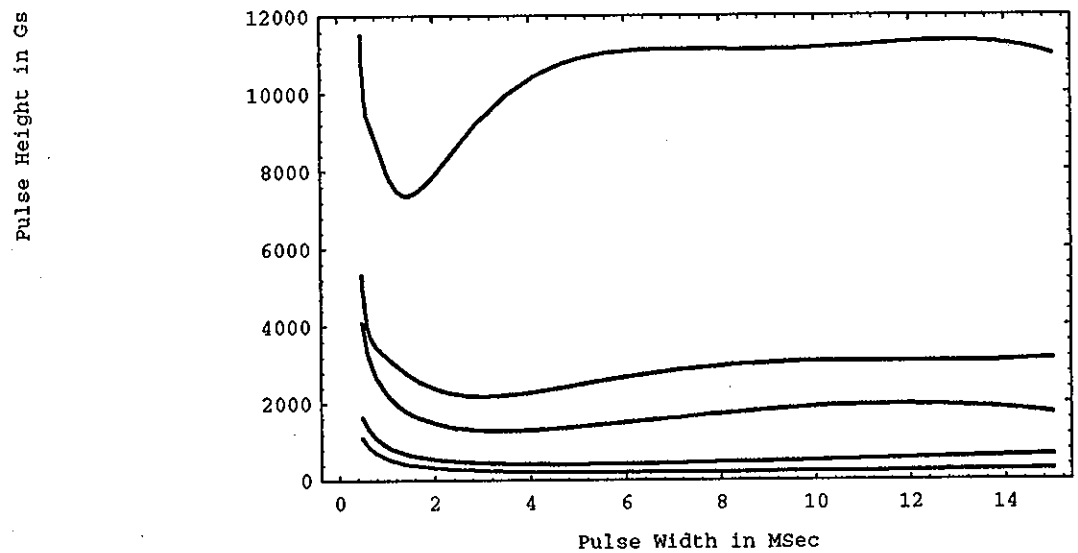
- Find the final curve, corrected for the intercept

$$22006.9 + \frac{8175.85}{x^4} - \frac{41047.9}{x^3} + \frac{74615.5}{x^2} - \frac{55732.3}{x} + 316.051\,x - 288.265\,x^2 + 27.9793\,x^3 - 0.828219\,x^4$$

- Display an overlay of the points and the fit



Display the overlay plot



Note: The curves (bottom to top) are for belt tensions of 0, 50, 200, 500(case 3), and 2000 lbf

```
<<Statistics`LinearRegression`;
Off[General::spell1]; Off[General::spell];
```

Obtaining the System Properties at 2000 lbf Belt Tension

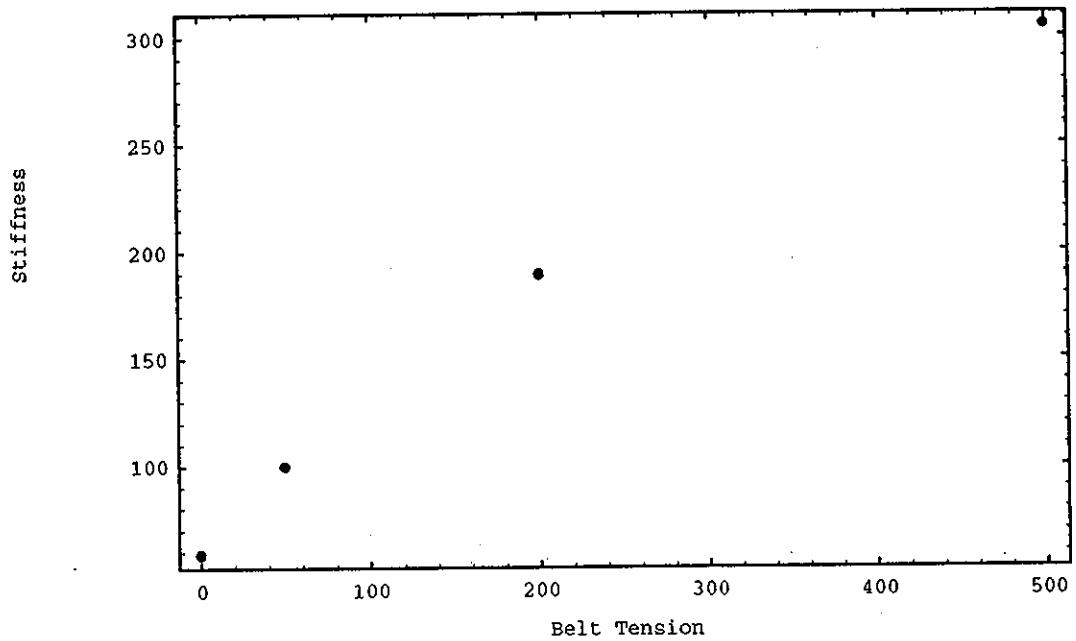
Stiffness and intercept data at various tensions

```
stiffnessvstension = {{0,58.6},{50,99.6},{200,189.1},{500,304.924}};
interceptvstension = {{0,1.224},{50,2.98},{200,6.85},{500,12.676}};
```

Model the stiffness behavior with belt tension

Plot the stiffness data

```
plota=ListPlot[stiffnessvstension,PlotJoined -> False,Frame->True,
FrameLabel->{"Belt Tension","Stiffness"},
 AxesOrigin -> {0.0,0.0}];
```



Find Linear model for stiffness

```
kt = Fit[stiffnessvstension,{1,x},x]
72.9696 + 0.480461 x
```

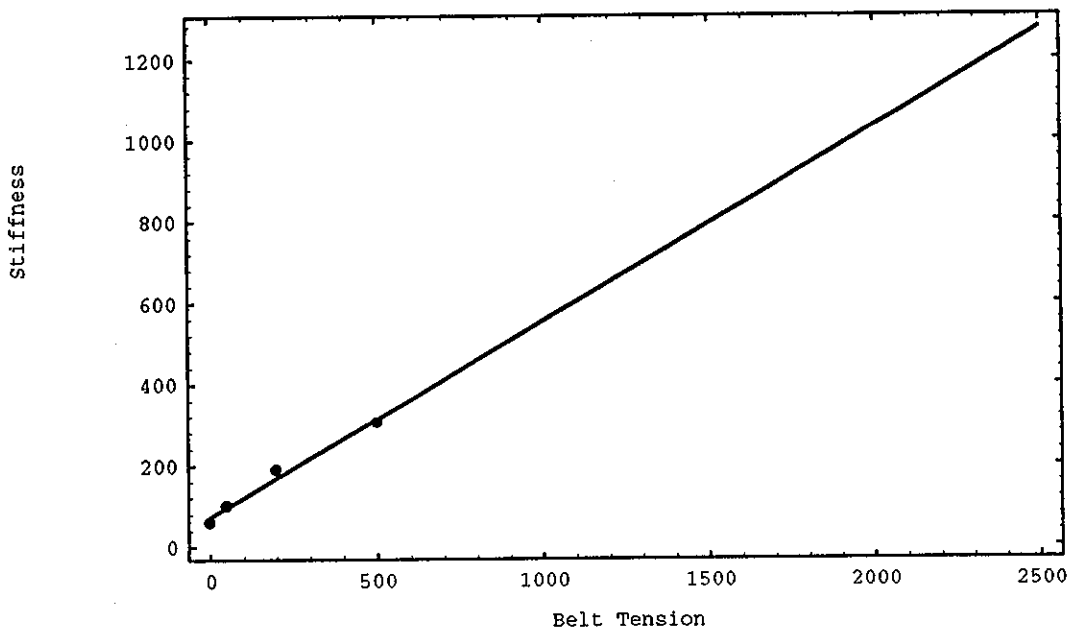
Find Regression Analysis values for the fit

```
Regress[stiffnessvstension,{1,x},x]
```

```
{ParameterTable ->      Estimate    SE          TStat     PValue     ,
                   1    72.9696     12.8257     5.6893    0.0295328

                   x    0.480461    0.0474296   10.13     0.00960486

 RSquared -> 0.980883, AdjustedRSquared -> 0.971324,

 EstimatedVariance -> 341.653,

 ANOVATable ->          DoF    SoS        MeanSS     FRatio     PValue     }
               Model    1      35059.2    35059.2    102.616    0.00960486

               Error    2      683.307    341.653

               Total    3      35742.5
```

■Show the data and the fit

```
plotb=Plot[kt,{x,0,2500},AxesOrigin->{0,0},Frame->True,
DisplayFunction->Identity];
plot1=Show[plota,plotb];
```



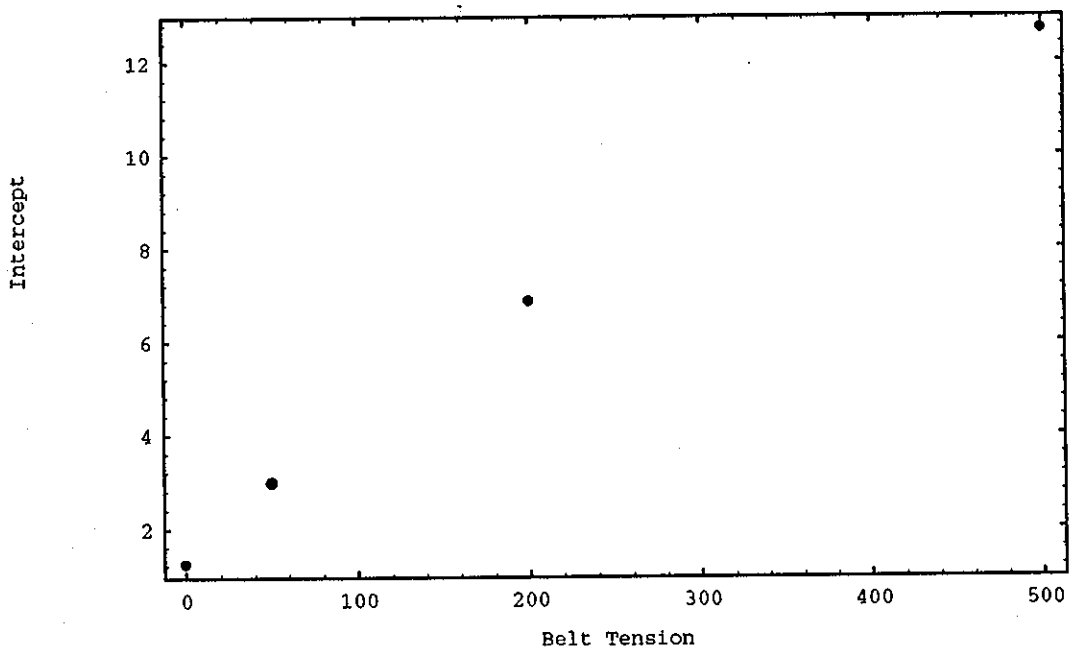
■Get the stiffness at 2000 lbf belt tension

```
kt/. x->2000
1033.89
```

Model the stiffness behavior with belt tension

Plot the intercept data

```
plotc=ListPlot[interceptvstension,PlotJoined -> False,Frame->True,
FrameLabel->{"Belt Tension","Intercept"},
 AxesOrigin -> {0.0,0.0}];
```



Find Linear model for intercept

```
interceptt = Fit[interceptvstension,{1,x},x]
1.72556 + 0.022437 x
```

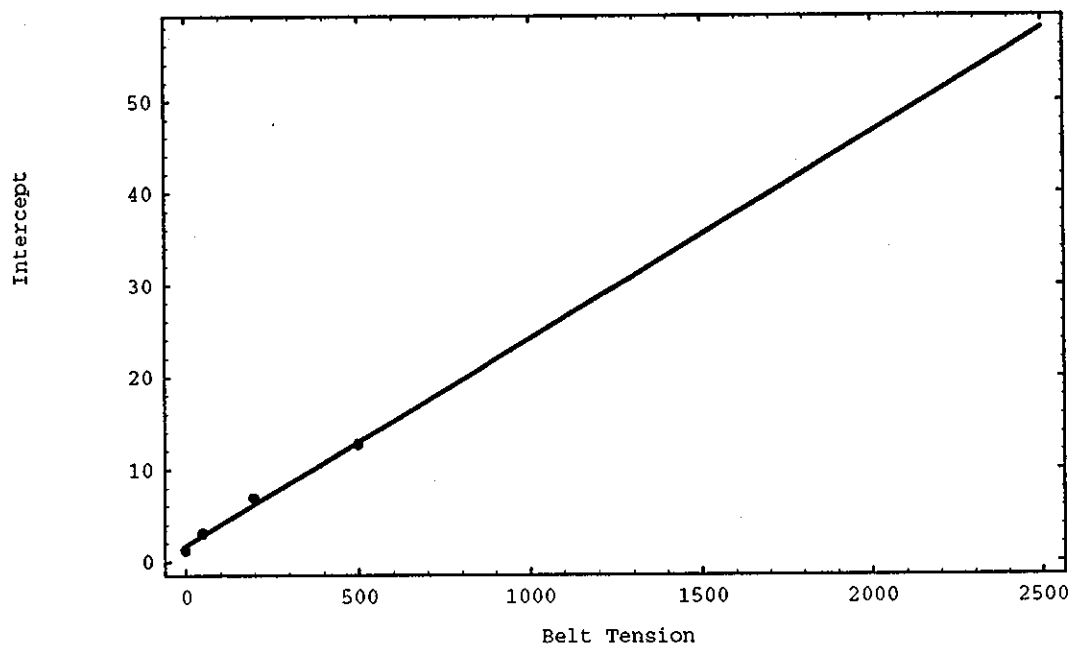
Find Regression Analysis values for the fit

```
Regress[interceptvstension,{1,x},x]
```

```
{ParameterTable ->      Estimate   SE            TStat      PValue      ,
                   1    1.72556    0.424016      4.06955    0.0554109

                   x    0.022437   0.00156801    14.3092    0.00484842

 RSquared -> 0.990327, AdjustedRSquared -> 0.98549,

 EstimatedVariance -> 0.373409,

 ANOVATable ->          DoF   SoS        MeanSS     FRatio     PValue     }
               Model    1     76.457     76.457     204.754    0.00484842

               Error    2     0.746819   0.373409

               Total    3     77.2038
```

■Show the data and the fit

```
plotd=Plot[interceptt,{x,0,2500},AxesOrigin->{0,0},Frame->True,
DisplayFunction->Identity];
plot2=Show[plotc,plotd];
```



■Get the intercept at 2000 lbf belt tension

```
interceptt/. x->2000
46.5996
```

Transient Response of a Moving Support Spring-Mass System

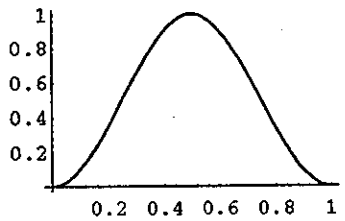
Define the acceleration pulse of the support

Formulation of the pulse

```
f[t_] := (1-Cos[2 Pi t/T]) G/2
```

Shape of the pulse

```
T=1;G=1;Plot[f[t],{t,0,T}];T=.;G=.;
```



Solve the Diff. Eqn. for time < pulse

```
sol1 = DSolve[{z''[t] + w^2 z[t] == -f[t], z[0] == 0, z'[0] == 0}, z,t];
d1[t_] := z[t] /. sol1; d1[t]
```

```
        2    2  2    2  2     2 Pi t        2
 G (4 Pi  - T  w  + T  w  Cos[------] - 4 Pi  Cos[t w])
                                T
{-----------------------------------------------------}
                    2        2    2  2
                2 w  (-4 Pi  + T  w )
```

Solve the Diff. Eqn. for time > pulse

```
sol2 = DSolve[{z''[t] + w^2 z[t] == 0, z[T] == d1[T], z'[T] == d1'[T]}, z,t];
d2[t_] := z[t] /. sol2; d2[t]
```

```
  -I T w        I T w     I t w    I (-t + T) w      2
 E       (-1 + E     ) (-E      + E             ) G Pi
{-----------------------------------------------------}
                        2  2    2  4
                   -4 Pi  w  + T  w
```

Obtain complete solution d[t] as the compression in the spring

```
d[t_]:= If[t<=T,d1[t],d2[t]]
```

Define the System: spring, mass, omega

```
k=kt/. x->2000 (*lbf/in*); m=0.0223 (*lbf*); w=Sqrt[12 k 32.2/m] (*ra/s*);
intercept=interceptt/. x->2000 (*lbf*);Print["k=",k," intercept=",intercept]
```

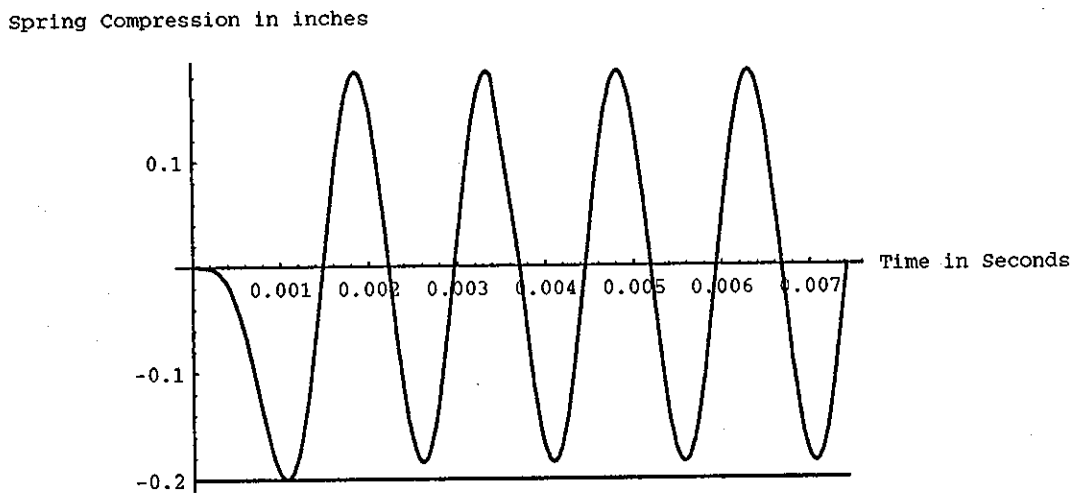
```
k=1033.89 intercept=46.5996
```

Define the pulse height and width, opening criteria

```
G=5438*32.2 (*ft/sec/sec*); T=1.48449/1000 (*sec*); failure=-0.2/12 (*ft*);
```

Plot the spring compression and failure criteria

```
plot1 = Plot[{12(d[t]),12failure},{t,0,5T}, PlotPoints ->25,
  PlotRange -> (*{-0.199,-0.201}*)All, AxesLabel -> {"Time in Seconds",
  "Spring Compression in inches"}];
```



Get (T,G) values for failure (Note: Here, T in msec, G in g's)

Note: These values were obtained by selecting a value of T and obtaining the minimum value of G which would make the two curves above (the compression and the st line at -0.2) touch. This was done by trial-and-error.

```
points2000g = {{.5,9433.5},{0.75,6906.5},{1,5909},{1.48449,5438},{2,5703.5},
{3,7003},{4,8660},{5,8819},{6,8706.5},{7,9097},{8,9091.5},
{9,9022},{10,9195},{11,9173},{12,9132.5},{13,9230.5},{13.5,9260},{14,9208.5}};
```