

System Redundancy Evaluation for Steel Truss Bridges

Youyou Cao

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Civil Engineering

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Description of item under review for fair use: Figure 2-1. Characteristics of one HS-20 truck. AASHTO (2010). LRFD Bridge Design Specifications. American Association of State Highway and Transportation Officials. Washington, D.C.

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Based on the information you provided:

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Name: Youyou Cao

Description of item under review for fair use: Figure 2-2. Transverse configuration of two side-by-side HS-20 trucks with a minimum spacing of 4 feet on the Beech Creek Veterans Memorial Bridge. Reese, L. D. (2009). Critical Member Removal and Load Redistribution of a Deteriorated Truss Bridge. Civil Engineering. Pennsylvania State University. Master of Science.

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Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

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Name: Youyou Cao

Description of item under review for fair use: Figure 2-3. Live load model of TT-43 with a total truck weight=43tf. JRA (2002). Specifications for Highway Bridges Part I: Volume on Common Matters. Japan Road Association.

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Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

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Description of item under review for fair use: Figure 2-4. Elevation view of the test span. Ocel, J. (2013). Evaluation of Member and Load-Path Redundancy on the US-421 Bridge over the Ohio River. Federal Highway Administration (FHWA). Washington D.C.

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Description of item under review for fair use: Figure 2-5. Close-up view of Interstate 80 Sign Truss. Wipf, T. J. and B. M. Phares (2002). Evaluation of Interstate 80 Sign Truss. The Iowa Department of Transportation. The Bridge Engineering Center at the Center for Transportation Research and Education-Iowa State University.

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Description of item under review for fair use: Figure 2-6. An illustration of the relationship between phantom nodes and original real nodes. Simulia (2010). Abaqus Analysis User Manual, Version 6.10, Providence, RI.

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Name: Youyou Cao

Description of item under review for fair use: Figure 3-1. A side view of the I-35W Bridge. NTSB (2009). Collapse of I-35W Highway Bridge, Minneapolis, Minnesota, August 1, 2007. National Transportation Safety Board.

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Description of item under review for fair use: Figure 3-2. Plan and elevation view of I-35W Bridge. Mn/DOT (2009). I-35W Bridge original plans & details. <http://www.dot.state.mn.us/i35wbridge/history.html>, Minnesota Department of Transportation.

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Description of item under review for fair use: Figure 3-3. Major components in the bridge truss system viewing in a transverse direction. NTSB (2009). Collapse of I-35W Highway Bridge, Minneapolis, Minnesota, August 1, 2007. National Transportation Safety Board.

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Description of item under review for fair use: Figure 3-4. 2D view of the idealized members and connections in the floor truss system. Ocel, J. M. and W. J. Wright (2008). Finite Element Modeling of I-35W Bridge Collapse Turner-Fairbank Highway Research Center.

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Description of item under review for fair use: Figure 3-5. 3D view of a global model in ABAQUS for the I-35W Bridge. Ocel, J. M. and W. J. Wright (2008). Finite Element Modeling of I-35W Bridge Collapse Turner-Fairbank Highway Research Center.

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Description of item under review for fair use: Figure 3-6. (a) Deflected shape of the bridge during collapse, looking northeast. NTSB (2009). Collapse of I-35W Highway Bridge, Minneapolis, Minnesota, August 1, 2007. National Transportation Safety Board.

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Description of item under review for fair use: Figure 4-2. Wreckage of member U10U11 on the East side of the main truss. NTSB (2009). Collapse of I-35W Highway Bridge, Minneapolis, Minnesota, August 1, 2007. National Transportation Safety Board.

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Description of item under review for fair use: Figure 4-3. An elevation view of connection U9 of member U8U9. Sverdrup & Parcel and Associates Inc. (1965). State of Minnesota Department of Highway Construction Plan for Bridge No. 9340 – Balance of Bridge and Approaches. St. Louis, MO.

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Description of item under review for fair use: Figure 4-5. Pure bending test set-up. Mohr, B. A. (2005). Investigation of Ultimate Bending Strength of Steel Bracket Plates. Masters of Science, Virginia Polytechnic Institute and State University.

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Description of item under review for fair use: Figure 4-7. Failure mode comparison between (a) the test specimen Mohr, B. A. (2005). Investigation of Ultimate Bending Strength of Steel Bracket Plates. Masters of Science, Virginia Polytechnic Institute and State University.

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Description of item under review for fair use: Figure 4-8. Strain gauge locations on the test specimen. Mohr, B. A. (2005). Investigation of Ultimate Bending Strength of Steel Bracket Plates. Masters of Science, Virginia Polytechnic Institute and State University.

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Description of item under review for fair use: Figure 7-2. A side view of the three-dimensional model for I-35-W Bridge in SAP2000. Lora, M. A. R. (2013). Study of the I-35W Highway Bridge Collapse Mechanism. Civil and Environmental Engineering, Virginia Polytechnic Institute and State University. Master of Science.

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Based on the information you provided:

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Description of item under review for fair use: Figure 7-3. Cross sectional view of one beam element drawn align the deck plane in SAP2000. Diggelmann, L. M., et al. (2012). Evaluation of Member and Load-Path Redundancy on the US-421 Bridge over the Ohio River. Purdue University.

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Description of item under review for fair use: Figure 7-4. Cross section with top center insertion point. Diggelmann, L. M., et al. (2012). Evaluation of Member and Load-Path Redundancy on the US-421 Bridge over the Ohio River. Purdue University.

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Description of item under review for fair use: Figure 7-8. A close-up view of the connection details for a typical X-brace assembly. Diggelmann, L. M., et al. (2012). Evaluation of Member and Load-Path Redundancy on the US-421 Bridge over the Ohio River. Purdue University.

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Description of item under review for fair use: Figure 7-38. Truss member connection details: (a) A shop drawing for a typical main truss to lower brace connection in the I-35W Bridge. Sverdrup & Parcel and Associates Inc. (1965). State of Minnesota Department of Highway Construction Plan for Bridge No. 9340 – Balance of Bridge and Approaches. St. Louis, MO.

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Description of item under review for fair use: Figure 7-66. The main span truss structure of the New River Bridge. Hickey, L. J., et al. (2009). Live Load Test and Failure Analysis for the Steel Deck Truss Bridge Over the New River in Virginia. Report No.: FHWA/VTRC 09-CR8. Virginia Transportation Research Council. Charlottesville, VA.

Report generated on: 10-01-2015 at : 14:51:20

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure 7-83. A steel grid deck fully filled with lightweight concrete. Modjeski and Masters (2011). Winona Bridge - Deck Rehabilitation Options.

Report generated on: 10-01-2015 at : 14:52:01

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure 7-84. A half-filled steel grid deck. Modjeski and Masters (2011). Winona Bridge - Deck Rehabilitation Options.

Report generated on: 10-01-2015 at : 14:52:39

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

(Questions? Concerns? Contact Gail McMillan, Director of the Digital Library and Archives at Virginia Tech's University Libraries: gailmac@vt.edu)

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure 7-85. Exodermic deck. Modjeski and Masters (2011). Winona Bridge - Deck Rehabilitation Options.

Report generated on: 10-01-2015 at : 14:53:30

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure A-1. Overall geometry of the truss system. Sverdrup & Parcel and Associates, Inc. (1965). State of Minnesota Department of Highway Construction Plan for Bridge No. 9340 – Balance of Bridge and Approaches. St. Louis, MO.

Report generated on: 10-01-2015 at : 14:54:45

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure A-2. Dimensions of brace members. Sverdrup & Parcel and Associates, Inc. (1965). State of Minnesota Department of Highway Construction Plan for Bridge No. 9340 – Balance of Bridge and Approaches. St. Louis, MO.

Report generated on: 10-01-2015 at : 14:55:23

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure A-3. Dimensions of floor truss members. Sverdrup & Parcel and Associates, Inc. (1965). State of Minnesota Department of Highway Construction Plan for Bridge No. 9340 – Balance of Bridge and Approaches. St. Louis, MO.

Report generated on: 10-01-2015 at : 14:56:22

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure B-1. Dimensions and design loads for floor truss members, stringers, and top lateral braces. J.G. White Engineering Corporation (1928).

Report generated on: 10-01-2015 at : 14:57:01

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure B-2. Dimensions and design loads for main truss members. J.G. White Engineering Corporation (1928).

Report generated on: 10-01-2015 at : 14:58:18

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure B-3. Dimensions and design loads for bottom lateral braces. J.G. White Engineering Corporation (1928).

Report generated on: 10-01-2015 at : 14:58:52

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

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Name: Youyou Cao

Description of item under review for fair use: Figure B-4. Dimensions and design loads for typical sway braces: (a) at the end panel points (U0 and U0'); (b) at intermediate panel points (U1 through U1'). J.G. White Engineering Corporation (1928).

Report generated on: 10-01-2015 at : 14:59:32

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure B-5. Design loads for main truss members and lateral braces. J.G. White Engineering Corporation (1928).

Report generated on: 10-01-2015 at : 15:00:10

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



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Virginia Tech ETD Fair Use Analysis Results

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Name: Youyou Cao

Description of item under review for fair use: Figure C-1. General information of the bridge geometry. The Commonwealth of Virginia, Department of Highways, Virginia Transportation Research Council (1941).

Report generated on: 10-01-2015 at : 15:00:50

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

This is not a replacement for professional legal advice but an effort to assist you in making a sound decision.

Name: Youyou Cao

Description of item under review for fair use: Figure C-2. Dimensions and design loads for truss members. The Commonwealth of Virginia, Department of Highways, Virginia Transportation Research Council (1941).

Report generated on: 10-01-2015 at : 15:01:23

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*



Draft 09/01/2009

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Virginia Tech ETD Fair Use Analysis Results

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Name: Youyou Cao

Description of item under review for fair use: Figure D-1. Dimensions and design loads for truss members. J.G. White Engineering Corporation (1928).

Report generated on: 10-01-2015 at : 15:02:00

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: *in favor of fair use*

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: *in favor of fair use*

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: *in favor of fair use*

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: *in favor of fair use*

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

