ENHANCED FUJITA SCALE

(EF Scale)

11A briefing presented to

NATIONAL WEATHER SERVICE

Silver Spring, Maryland

June 28, 2004

Wind Science and Engineering Center

Texas Tech University

Theodore T. Fujita

Limitations of Fujita Scale

- Difficult to apply consistently
- Not enough damage indicators
- Does not account for construction quality
- No definitive correlation between damage and wind speed

Fujita Scale Enhancement Project

- WISE agreed to initiate project
- Funding was available through NIST
- Co-PI's each have more than 30 years experience with tornado damage

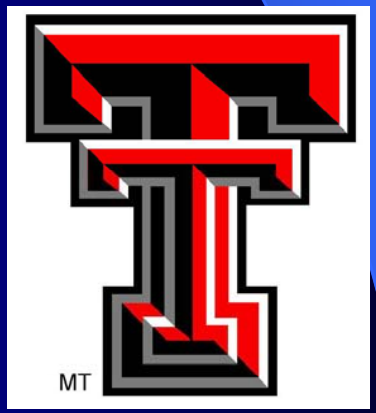
Co-PI's

James R. McDonald, Ph.D., PE.

- Tornado damage documentation experience
- Tornado hazard assessment
- Tornado damage mitigation

Kishor C. Mehta, Ph.D., P.E.

- Director of WISE (Retired)
- Chair ASCE 7 Wind Load Task Committee
- Internationally recognized researcher



WISE Strategy

- Choose a steering Committee
- Involve many users
- Develop a plan
- Obtain a consensus

Steering Committee

Member	Title	Organization
Jim McDonald	Professor	Texas Tech University
Kishor Mehta	Director	Wind Science & Engineering Center
Don Burgess	Assistant Director	National Severe Storms Lab
Joe Schaefer	Director	Storm Prediction Center
Michael Riley	Engineer	National Institute of Standards and Technology
Brian Smith	Meteorologist	National Weather Service

Steering Committee Objectives

- Organize a forum of users
- Identify key issues
- Recommend a new or modified Fujita Scale
- Develop strategies to obtain a consensus

Fujita Scale Forum

- March 7-8, 2001
- Grapevine, Texas
- 20 of 26 invited participants attended
- Developed strategies for an enhanced Fujita Scale

Strategies

- Define additional damage indicators
- Correlate appearance of damage with wind speed
- Preserve historical tornado data base
- Obtain input from users

Damage Indicators (DI's)

- WISE team proposed 28 DI's
- Buildings, structures and trees
- DI's described in detail
- Additional DI's can be added in future

Degrees of Damage (DOD's)

- Each DI has several degrees of damage
- DOD's range from no damage to total destruction
- DOD's are arranged in order of increasing damage
- They are a function of wind speed

Correlation of Damage and Wind Speed

- Need expected, upper and lower bound wind speeds for each DOD
- Expected wind speed based on “normal” conditions
- Upper and lower bound wind speeds represent possible deviation from the “normal” situation

Approach

- Deterministic
- Monte Carlo
- Expert elicitation

Expert Elicitation

- Used successfully for estimating seismic physical parameters
- Senior Seismic Hazard Assessment Committee (SSHAC – 1997)
- Experts make best estimates of expected, upper and lower bound wind speeds
- Follow a well-defined protocol
- The end result is the best possible estimate of the desired parameter

SSHAC Elicitation Process

- Describe DI's and DOD's
- Identify and engage a panel of experts
- Discuss issues with experts; provide data
- Train experts in elicitation process
- Conduct individual elicitations and group interactions

SSHAC Elicitation Process

- Analyze and aggregate elicitations and resolve issues
- Refine wind speed estimates with several iterations
- Document and communicate process and final results
- Obtain additional peer review of process and results

Elicitation Experts

Name	Expertise	Organization
Greg Forbes	Meteorologist	Weather Channel
Don Burgess	Meteorologist	NSSL
Doug Smith	Engineer	WISE
Tim Reinhold	Engineer	Clemson University
Tom Smith	Architect	Consultant
Tim Marshall	Meteorologist/ Engineer	Haag Engineers

Elicitation Procedure

- Wind speeds are 3-second gusts at 10 m in flat open terrain
- Experts met for one and one-half days
- Conducted 3 rounds of elicitation

Results of Elicitation

- Name and description of DI
- DOD's and estimated wind speeds
- Order DOD's by increasing wind speeds
- Plot DOD's versus wind speed
- Provide photo examples of DOD's

One-and Two-Family Residences (FR12)

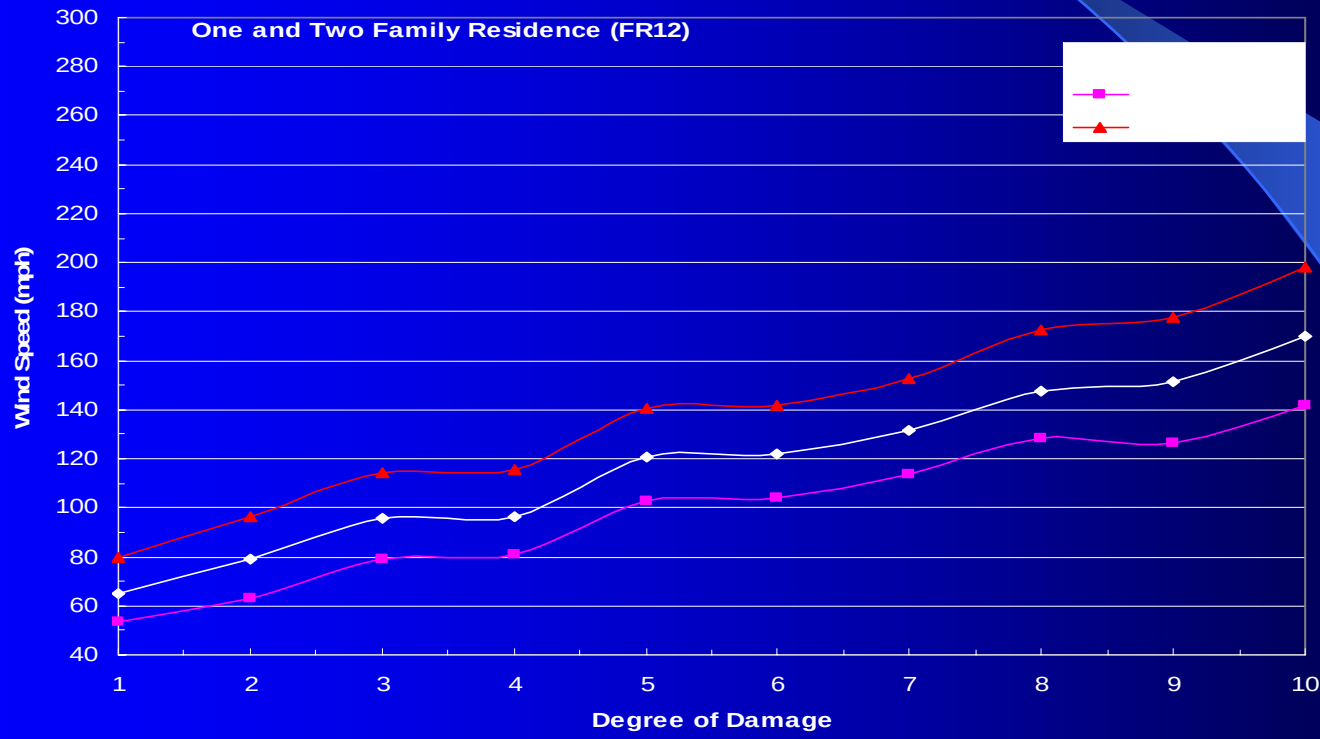
Typical Construction:

- **Asphalt shingles, tile, slate or metal roof covering**
- **Flat, gable, hip, mansard or mono-sloped roof or combination thereof**
- **Plywood/OSB or wood plank roof deck**
- **Prefabricated wood trusses or wood joists and rafter construction**
- **Brick veneer, wood panels, stucco, EIFS, vinyl or metal siding**
- **Wood or metal stud walls, concrete blocks or insulating concrete panels**
- **Attached single or double garage**

One-and Two-Family Residences (FR12)

DOD	Damage Description	Exp	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Top floor exterior walls collapsed	132	113	153
8	Most interior walls of top story collapsed	148	128	173
9	Most walls collapsed in bottom floor, except small interior rooms	152	127	178
10	Total destruction of entire building	170	142	198

One-and Two-Family Residences (FR12)



1 mph = 0.447 m/s

One-and Two-Family Residences (FR12)

FR12: DOD4: Uplift of roof deck and loss of roof covering (>20%); garage door collapses outward

One-and Two-Family Residences (FR12)

FR12: DOD6: Large sections of roof removed; most walls remain standing

One-and Two-Family Residences (FR12)

FR12: DOD7: Top floor (First floor in this case) exterior walls collapsed

One-and Two-Family Residences (FR12)

FR12: DOD10: Total destruction of entire building

Correlation of Fujita Scale and EF Scale

- Used a second group of experts
- They assigned Fujita Scale categories to each DOD
- Ratings were converted to 3-second gust median wind speeds
- Obtained average of Fujita Scale wind speeds

Correlation of Fujita Scale and EF Scale

- Performed a regression analysis to obtain correlation between average Fujita Scale and expected EF Scale wind speeds
- Regression equation:

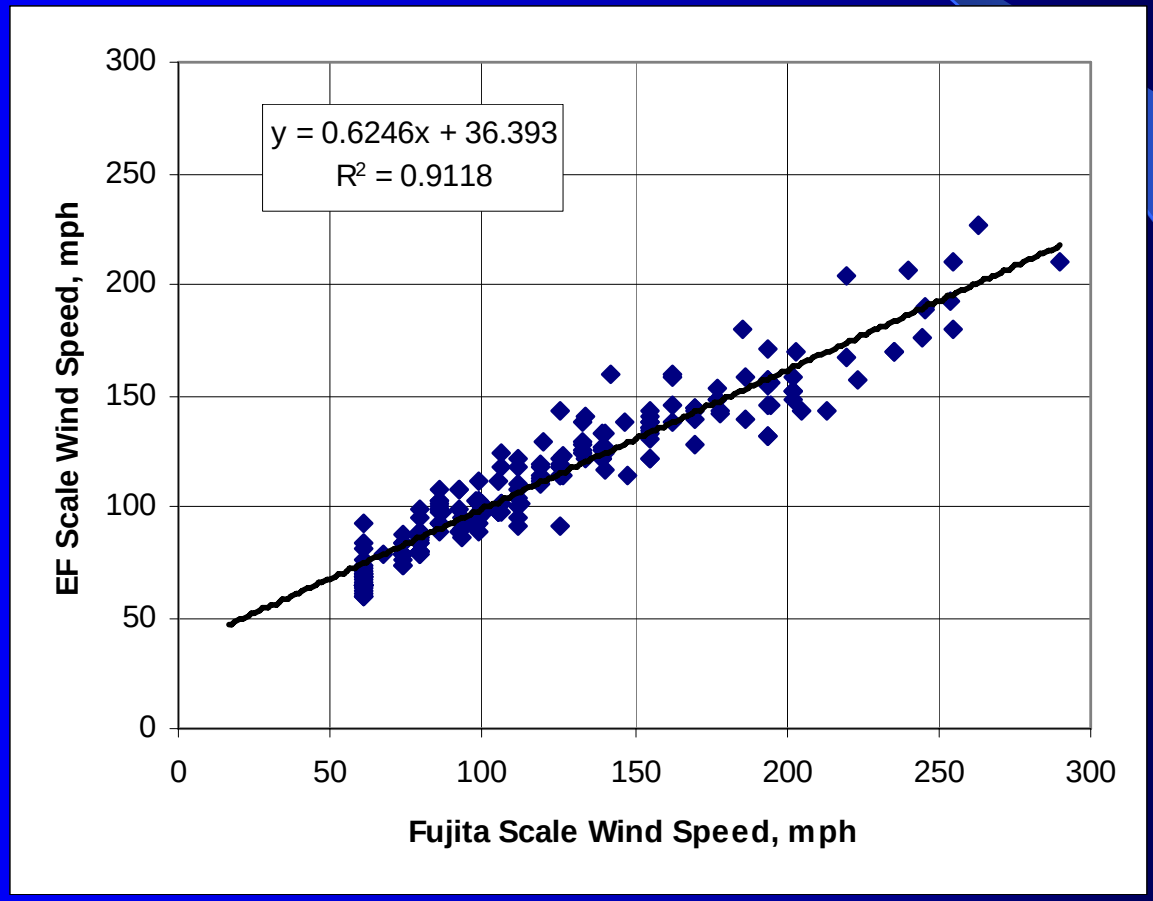
$$y = 0.625x + 36.4$$

where $y = \text{EF Scale wind speed}$

and $x = \text{Fujita Scale wind speed}$

Correlation Coefficient $R^2 = 0.91$

Correlation of Fujita Scale and EF Scale Wind Speeds



Derived EF Scale Wind Speed Ranges

Fujita Scale			EF Scale	
Fujita	Fastest 1/4/-mile	3-Second Gust	EF	3-Second Gust
Scale	Wind Speeds, mph	Speed, mph	Scale	Speed, mph
F0	40 - 72	45 - 78	EF0	65 - 85
F1	73 - 112	79 - 117	EF1	86 - 109
F2	113 - 157	118 - 161	EF2	110 - 137
F3	158 - 207	162 - 209	EF3	138 - 167
F4	208 - 260	210 - 261	EF4	168 - 199
F5	261 - 318	262 - 317	EF5	200 - 234

Recommended EF Scale Wind Speed Ranges

Derived EF Scale		Recommended EF Scale
EF	3-Second Gust	3-Second Gust
Classes	Speed, mph	Speed, mph
EF0	65 - 85	65 - 85
EF1	86 - 109	86 - 110
EF2	110 - 137	111 - 135
EF3	138 - 167	136 - 165
EF4	168 - 199	166 - 200
EF5	200 - 234	>200

EF5 Wind Speed Range

- We recommend no upper bound on this category
- Physical upper bound tornado wind speed not known
- Will avoid folks assuming worst case scenario for EF5 category

Rating an Individual Building

- Find DI that matches the building type and construction
- Observe the damage and match to one of the DOD's
- Determine if wind speed to cause observed damage is higher, lower or equal to the expected value within the wind speed range

Rating an Individual Building

- The assigned EF Scale rating is the one whose range of wind speed contains the estimated wind speed to cause the DOD.
- Additional DI's should be considered in assigning and EF Scale to a tornado event

Rating a Tornado Event

- Conduct an aerial survey to identify potential DI's and to define extent of damage path
- Identify 2 or more DI's that seem to indicate the highest wind speed in the path
- Locate these DI's within the damage path
- Follow steps for individual buildings or structures and document results

Rating a Tornado Event

- Considering several DI's, estimate maximum tornado wind speed
- Assign EF Scale category based on the maximum estimated wind speed
- Record basis for EF Scale rating
- Record other pertinent data relating to the tornado event

Presentations and Workshops

- Fujita Symposium, January 2000
- National Severe Storms Workshop, March 2001
- U.S. National Conference on Wind Engineering, June 2001
- AMS National Conference, January 2002
- 21st Conference on Severe Local Storms, August 2002
- 11th International Conference on Wind Engineering, June 2003
- 22nd Conference on Sever Local Storms, October 2004 (Paper accepted)

WISE Website

www.wind.ttu.edu

Conclusion

- We have followed the strategies of steering committee and forum
- Provided additional damage indicators
- Established correlation between damage and wind speed
- Determined correlation between Fujita and EF Scales
- Presented our work in a number of venues