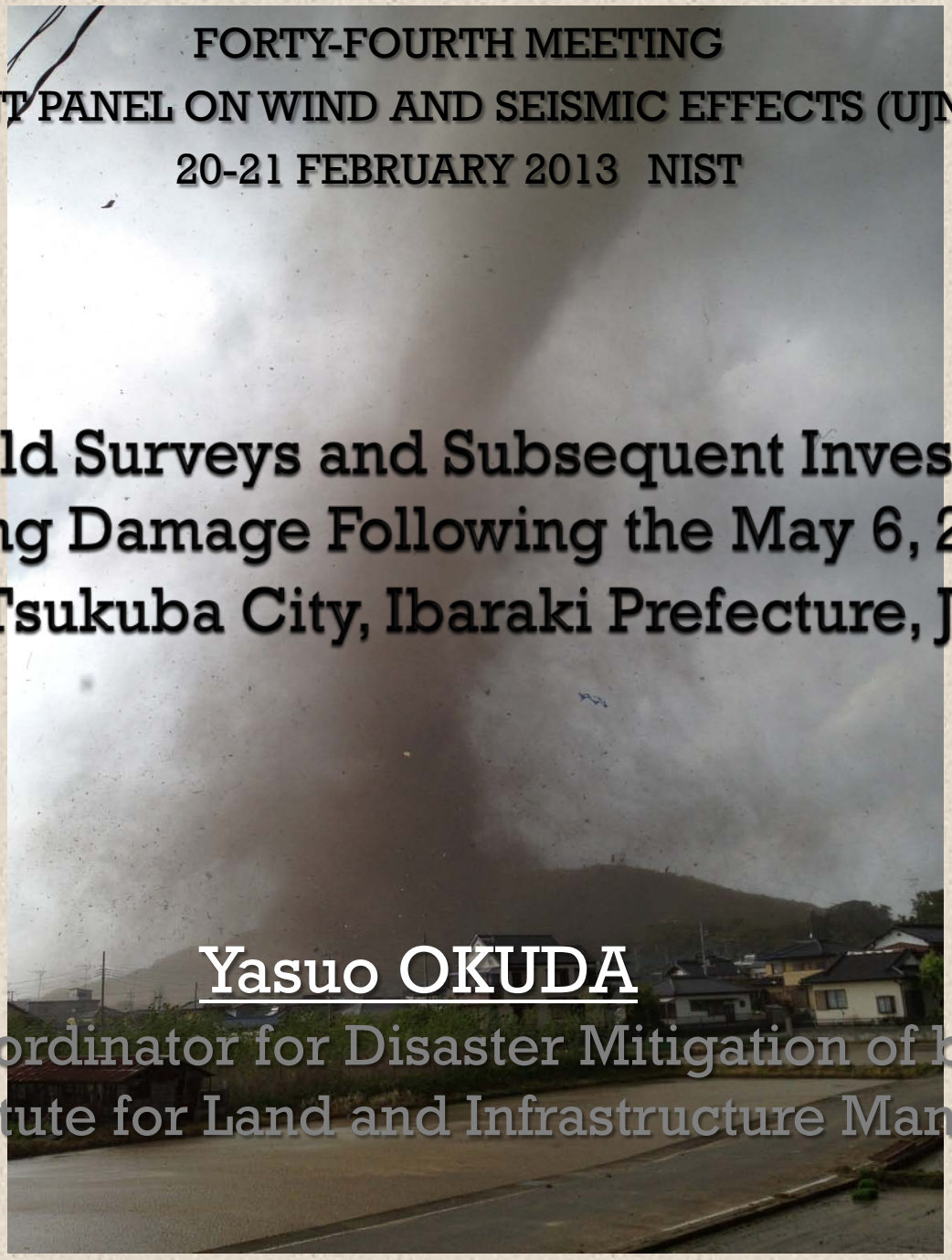
FORTY-FOURTH MEETING

JOINT PANEL ON WIND AND SEISMIC EFFECTS (UJNR)

20-21 FEBRUARY 2013 NIST



Report on Field Surveys and Subsequent Investigations of Building Damage Following the May 6, 2012 Tornado in Tsukuba City, Ibaraki Prefecture, Japan

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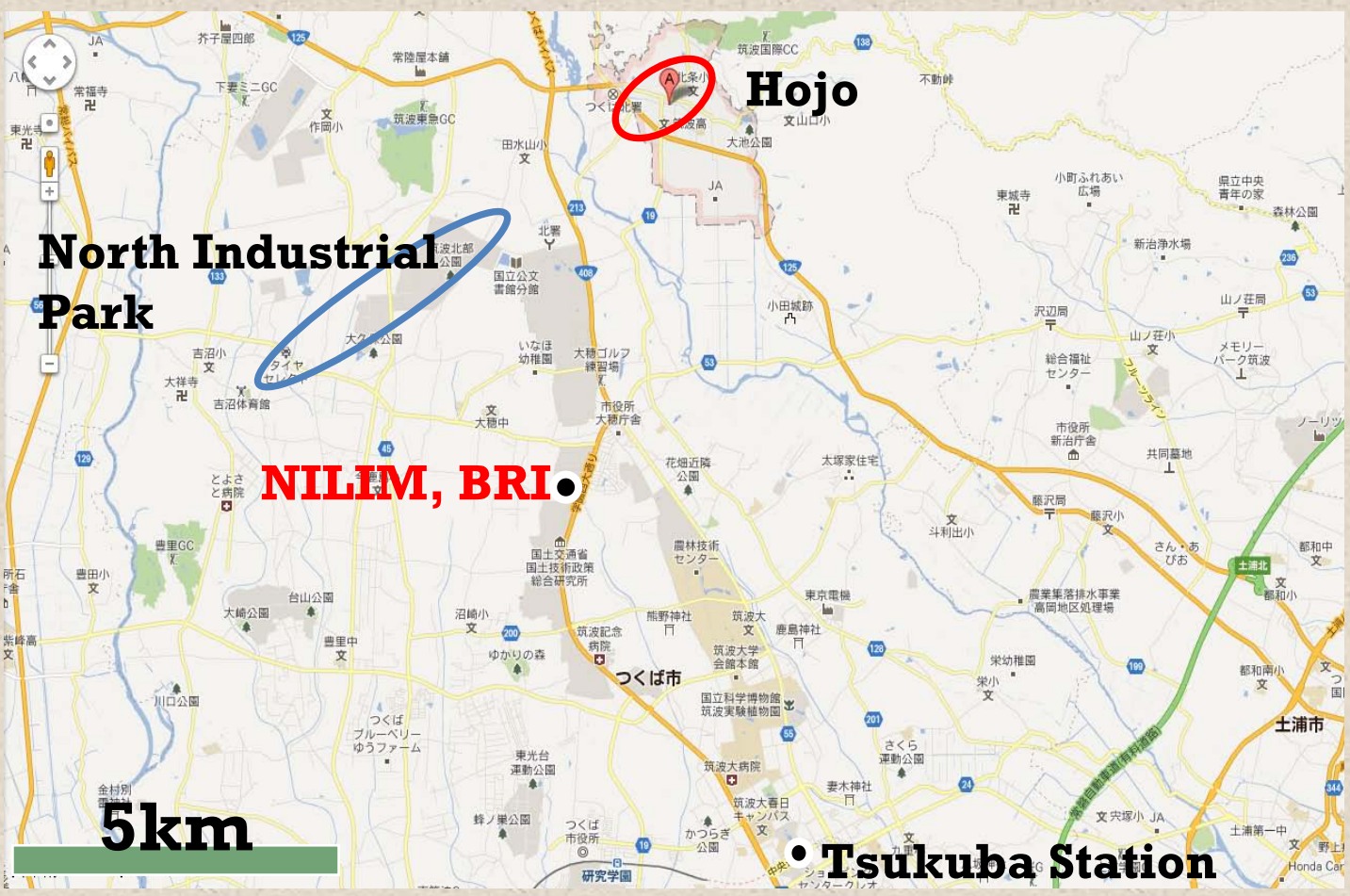
1 .Summary of Damage

- At around 12:35 p.m. on May 6, 2012,(holiday) a tornado formed in Joso City, Ibaraki Prefecture and moved toward Tsukuba City.
- Meteorological Agency Japan acknowledged that the tornado was estimated to be of the F3 class on the Fujita Scale, based on the degree of damage.

	Dead	Serious Injuries	Moderate Injuries	Light Injuries
Tsukuba	1	0	5	32
Joso	0	0	0	0

		Completely destroyed	Nearly completely destroyed	Partial collapse	Light damage	Subtotal	Total
Tsukuba	Residential	89	35	143	384	651	1093
	Non-residential	121	12	54	255	442	
Joso	Residential				12	12	28
	Non-residential				16	16	

2． Location of Damage area



- Tornado ran about 5km near NILIM and BRI.
- NILIM and BRI took field surveys in Tsukuba City immediately after the tornado in order to evaluate the state of damage to buildings and other structures.

Ranking of wind damage

Tsukuba

Rank 1 (Extremely minor damage)

Home television antennas are bent. Gutters have fallen off roofs. Small branches are broken, and leaves are strewn about.

89

Rank 2 (Light damage)

Roof tiles are knocked out of place. Roof tiles, shingles, metal roofing materials are partially (less than 30% of roof area) strewn about by eaves, verges, etc. Large branches are broken.

181

Rank 3 (Severe damage)

Tiles, shingles, metal roofing materials, etc., from a wide area of the roof (more than 30%) have been knocked off, and a large area of sheathing roof boards is visible. Some windows are broken. Minor damage to exterior walls. Large trees have fallen over.

149

Rank 4 (Major damage)

There is damage to roof rafters, purlins, etc. Roof trusses are torn apart. Numerous windows are broken.

78

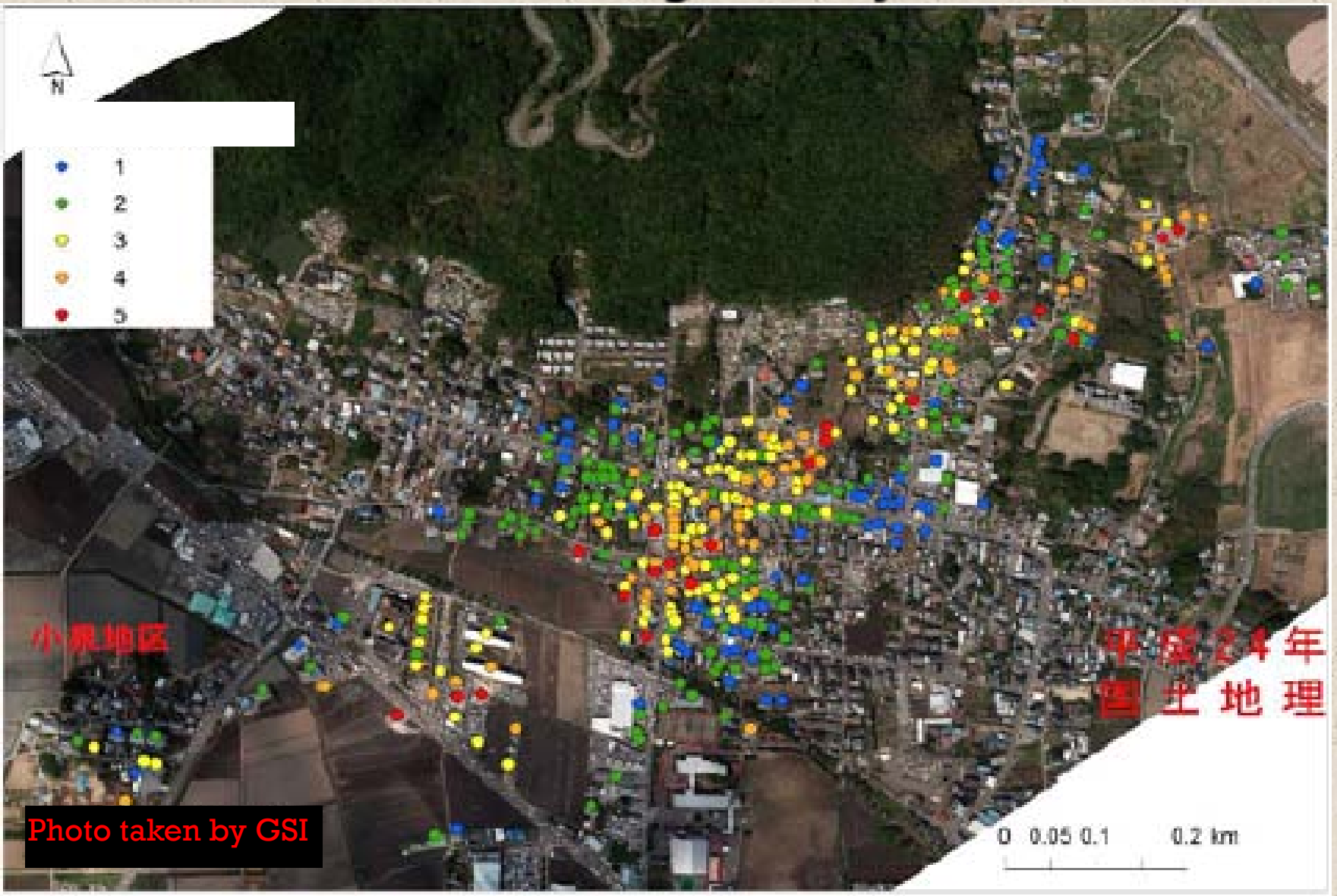
Rank 5 (Devastating destruction)

Homes/buildings have collapsed.

51

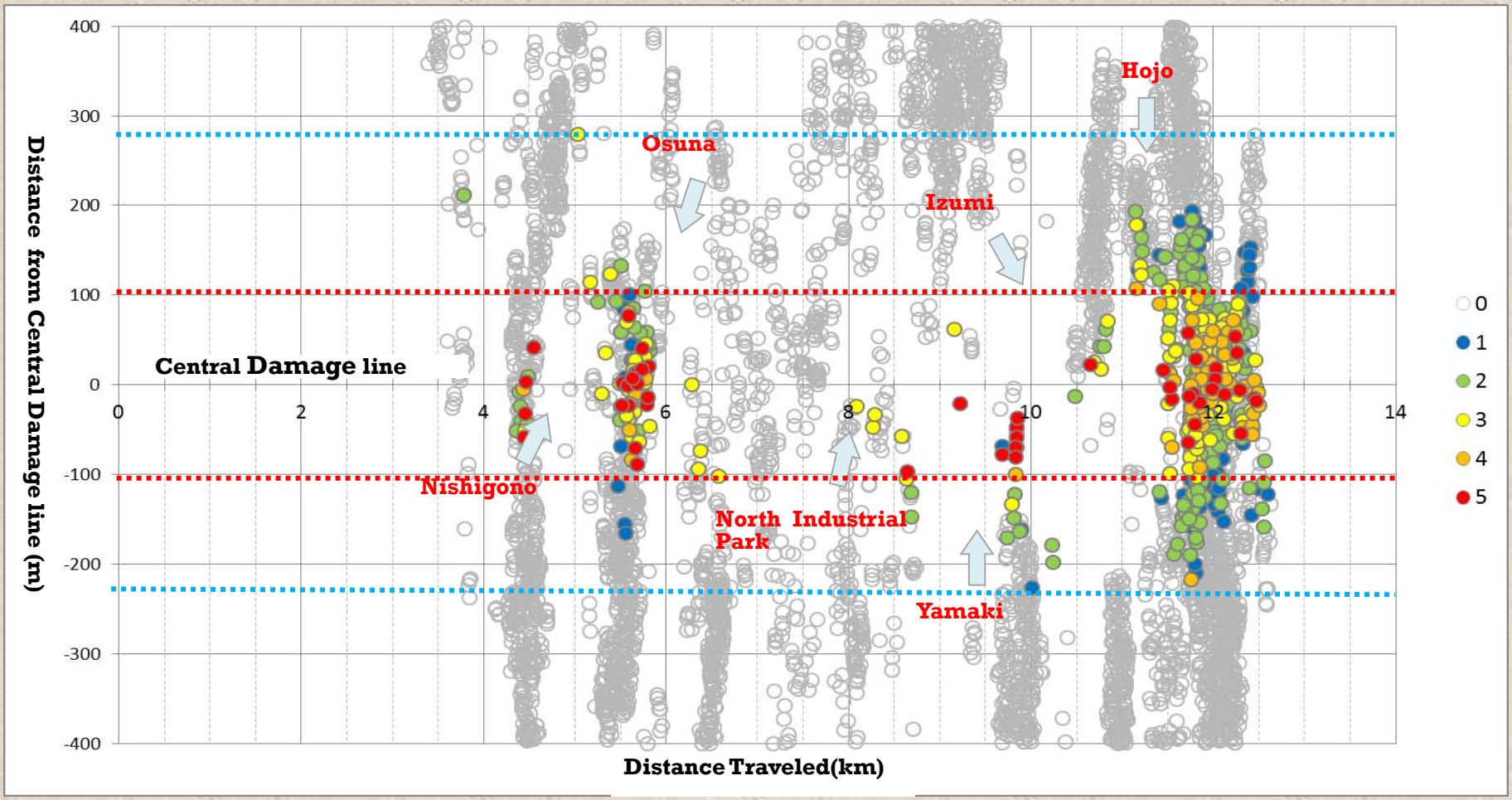
All damaged buildings in Tsukuba city were estimated using a ranking of wind damage, which Okuda, Kikitsu and Nishimura (2006) proposed.

Distribution of Damage in Hojo District



- Estimation of Damage to Buildings by Ranking of Wind Damage

Distribution of Building Damage in Tsukuba



- Central Damage line : Approximate line of all damaged buildings
  Maximum Width≒500m
  Width of Severe damaged area≒200m

Central damage line and central path of tornado

- Central path of the tornado: Miyagi (2012) estimated it from the tornado images taken from the area surrounded by dotted red line.
- The central damage line and the estimated central path of the tornado are roughly parallel to each other, with the central damage line proceeding about 35 m to the right side of the central path of the tornado. Assuming the Rankin vortex model for the tornado, maximum wind speed radius was estimated to be nearly 35m in the dotted red circle .

3 . STATE OF DAMAGE TO BUILDINGS

(1)Overturned superstructure with foundation

The condition of the second floor of 2 story wooden house (about 2 year old) confirmed that it had been flipped upside down, but the roof truss and the first floor section could not be found.

An aerial photo confirmed that members on the right side of the tornado's traveling direction were scattered about.

Scattering of the superstructure

Superstructures of 2 house in the front of the 5 story RC apartment building, were completely scattered to the apartment building.

1st story floor of the structure remained.

Foundation (corner section) of the structure remained.

(3) Collapse and other damage of superstructures

An old wooden house was collapsed.

A new wooden warehouse was collapsed but roof tiles which were not so much damaged were hastened with screw nails.

(4) Damage to roof trusses

Numerous examples of damage to roof trusses were found. Wind pressure coefficients on the roofs are changed according to the shape of the roof. However, it was determined that damage was not related to the roof shape.

Gable roof

Hip roof

Pent roof

Damage to Steel-Frame Buildings

Residual deformation of Steel-frame structure

Overturning of car port

Damage to Exterior of Wooden Buildingr

Displaced roof tiles

Failure of openings

External finishing fall off

Damage to Exterior and Interior of Engineered Building

Finishing materials torn off the underside of a walkway

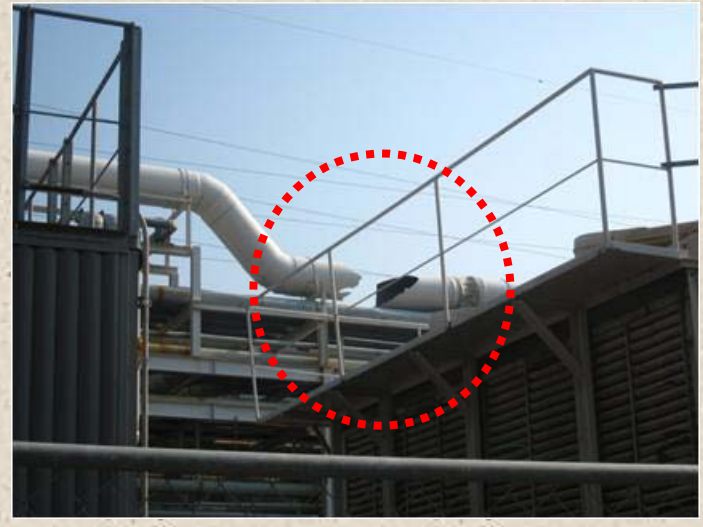
Damage to interior materials

Damage to a ceiling

Damage to Exterior of 5 story RC apartment building

There was remarkable damage extending to all floors facing the south of the building by wind pressure and flying debris.

Damage to Exterior of other buildings



North Industrial Park

Vehicles and trees

Flying debris

Damage state induced by flying debris

Damage to openings of School building

Another tornado hit a school building in Moka City. There no person in all class rooms because that date was holyday. Tornadoes attacked school buildings in Toyohashi(1999), Saga(2004), Moka(2012) and so on. Ministry of Education, Culture, Sports, Science & Technology (Mext) proposed an incentive to reduce the disaster in school buildings such as introduction of laminated glasses to openings.

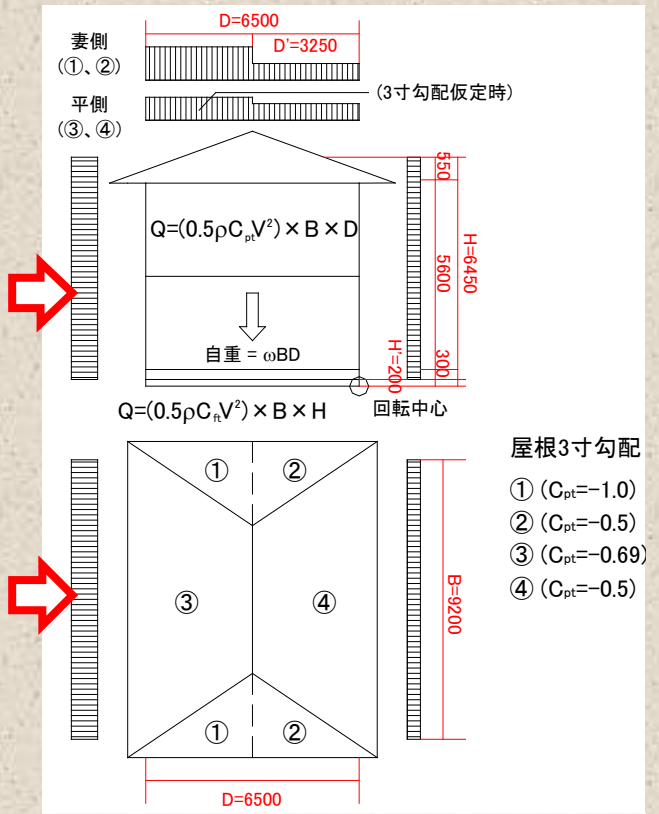
Estimation of Wind Velocity Based on Damage Pattern in Buildings

-Example of Collapsed Wooden Buildings

<u>State of a mat foundation</u>
The foundation was completely reversed. Damaged stepping-stones of the entrance was remained.

<u>Condition of crushed stone under the foundation</u>
There were almost no traces of the crushed stone beneath the foundation having been dragged. Outdoor units of an air conditioner was remained.

Scenario 1



width × depth × height　9.2 × 6.5 × 6.45m
weight≒630kN

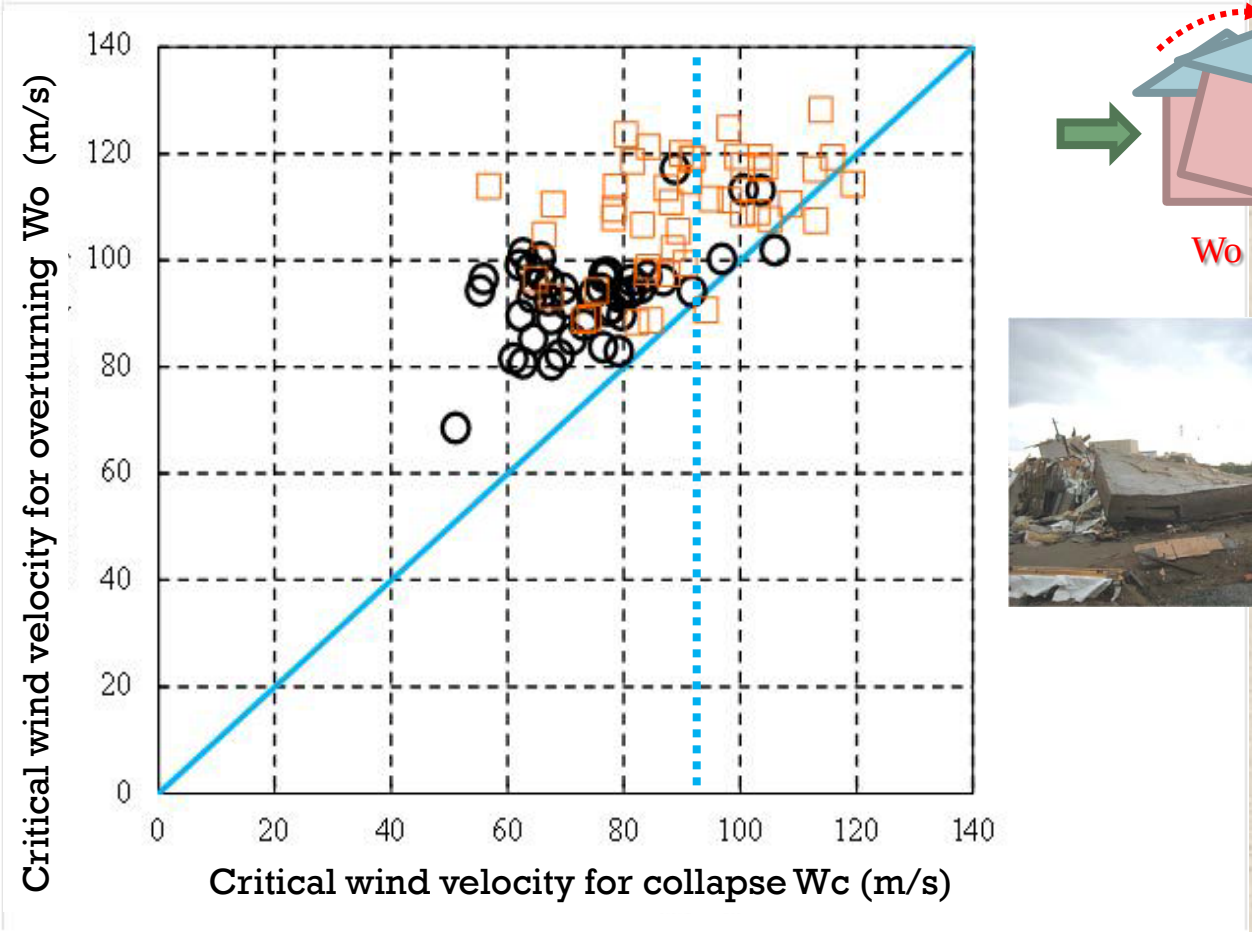
Wind pressure coefficients are measured in wind tunnel experiments or BSL

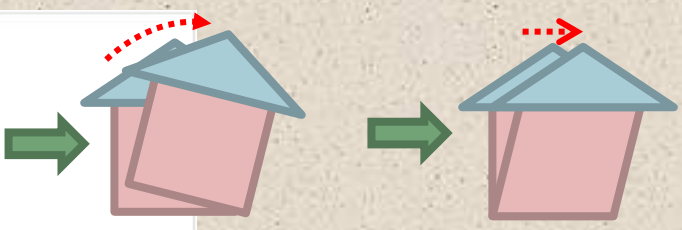
C_{fx}	C_{fz}
1.2	-1.0
	-0.5
	-0.69
	-0.5

<u>Usual estimation of tornado wind velocity</u>

If horizontal uniform wind acted on a house, the critical wind velocity at the start of overturning of the house was calculated as about 97m/s (F4).

Test calculation of Critical Wind Velocity of 53 Japanese wooden houses



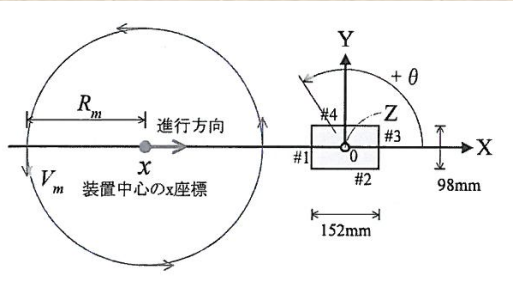


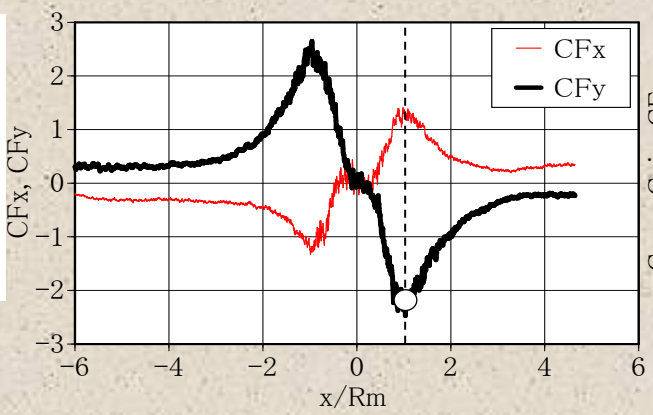
Wo > Wc

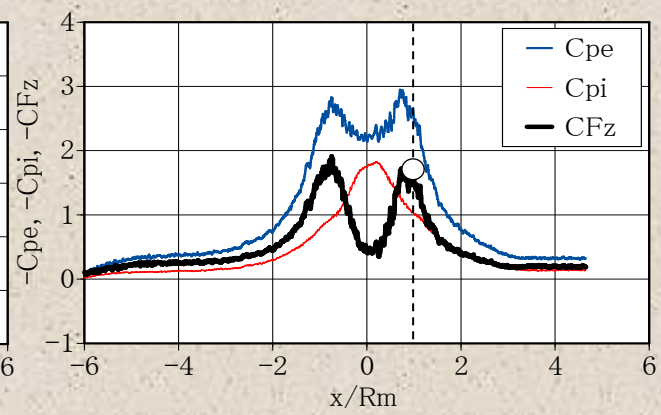
Relationship between wind velocity Wc when the houses collapse from loss of horizontal resistance and wind velocity Wo when they are overturned in the uniform flow.

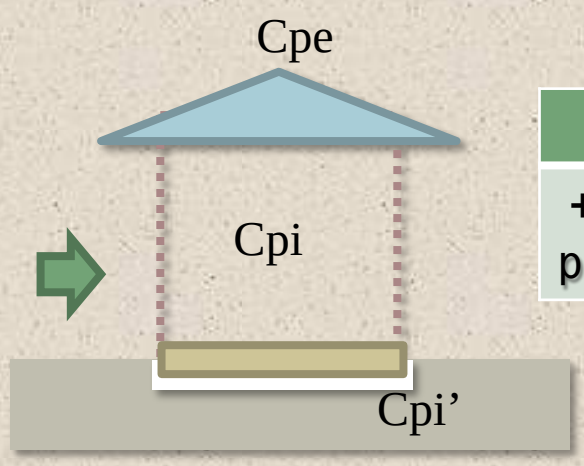
Wo>Wc in the almost cases. It means that generally Japanese wooden houses collapse before they overturn.

Scenario 2 (Tornado Simulator results)









	C_{fx}	C_{fz}
＋difference of atmospheric pressures	1.2~2.0	-1.8

2) If the maximum wind force for vertical direction is estimated as the difference of atmospheric pressures of tornado（$C_{fz} = C_{pe} - C_{pi} = C_{pe} - C_{pi}'$: C_{pe} on the roof and C_{pi}' under the foundation), based on the results of the tornado simulator, the critical wind velocity at the start of overturning was about 78m/s or 68m/s.

Experimental conditions are in Table 1.

5. Conclusion and Future Task

- Summary of Damages

  More than 1000 buildings were damaged.
- Damage of Distribution in Tsukuba City

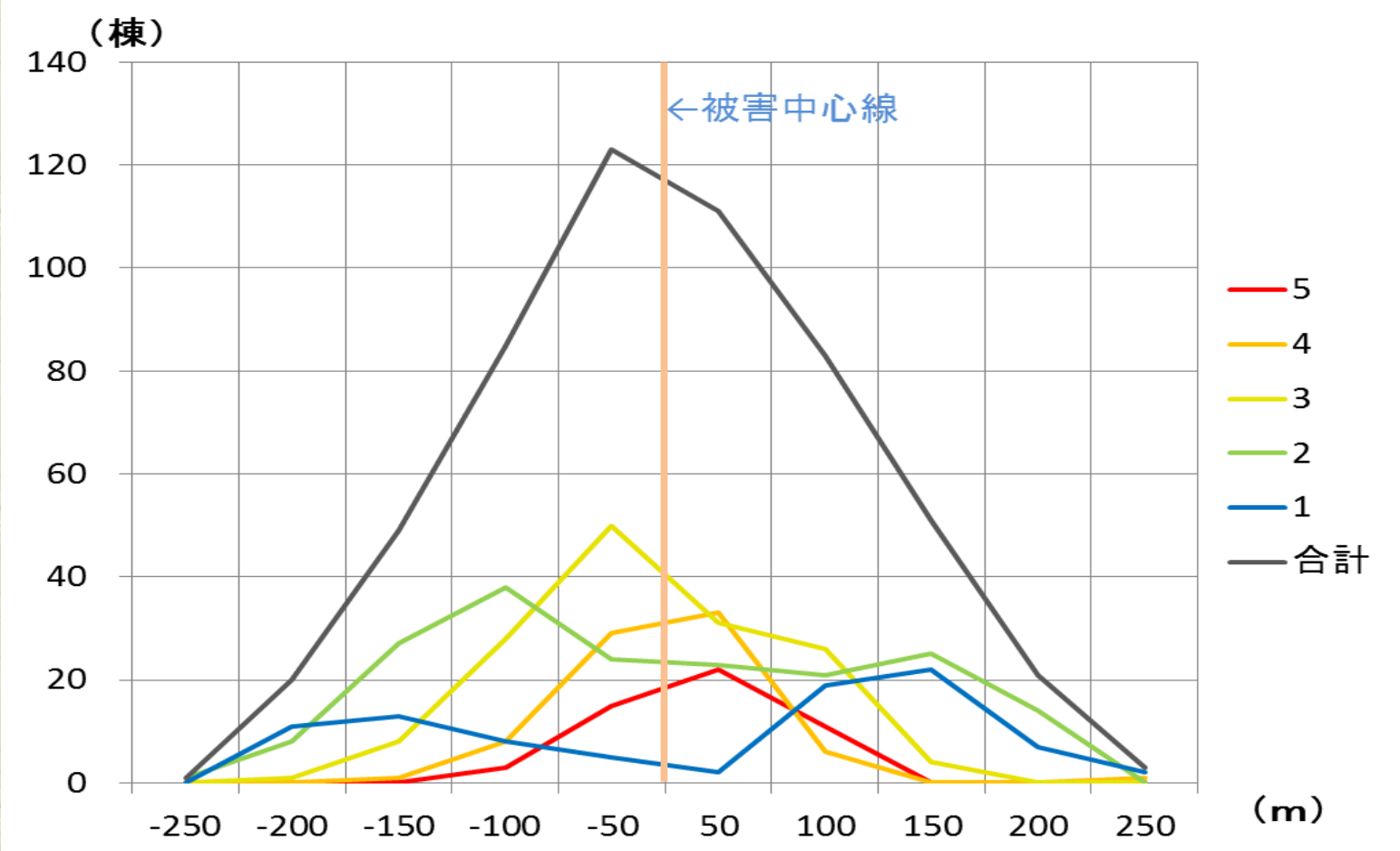
  Width of severe area was about 200m. Maximum wind velocity radius of the tornado was about 35m.
- State of Damage to Buildings

  Overturned, Scattered, Collapse of superstructure were observed.
- Estimation of Wind Velocity Based on Damage Patterns in Buildings

  Critical wind velocity was estimated for the overturning house and so on.

- Development of Tornado loads for special buildings
- Development of estimation method of components and claddings for Japanese flying debris including Japanese roof tiles

つくば市全域の建築物等の被害分布



- 強風被災度ランクによる被害評価
  ランク４・５：被害中心よりも右側にピークをもつ分布
  ランク１・２：中心付近が窪んだ二山の分布

被害状況

被災状況一覧

強風被害度ランク	被害棟数
ランク⑤ (壊滅的な被害)	21
ランク④ (甚大な被害)	66
ランク③ (顕著な被害)	108
ランク② (軽微な被害)	141
ランク① (極く軽微な被害)	73
計	409

歷史的建築物137棟のうち85棟が被災。
同地区の一般建築物と比較すると被害程度は小さい。
全壊2棟は門で、主な被害は、瓦・トタンの破損、開口部の破損
用途別の被災：店舗21棟、住宅28棟、蔵23棟、門納屋等13棟

2001年

被災後

2001年

被災後

2001年

被災後

被災後の修復（応急処置）によって保存された例

屋根瓦だけが飛散したものが多かった理由

1）土を用いた瓦葺きで、経年劣化により葺き材と下地が一体化した構造でなかったものも多い

土蔵造り建物の被害が少なく、最も被害の多い地域でも軸組に影響が見られなかった理由

1）土蔵造りは重量の重い構造であること

2）建具が木製建具で遊びがあり、風によって建具だけが破壊され軸組が大きな荷重の負担を免れたこと

写真

2001年＝後藤藤研究室撮影。

被災後＝筑波大学安藤研究室、藤川研究室

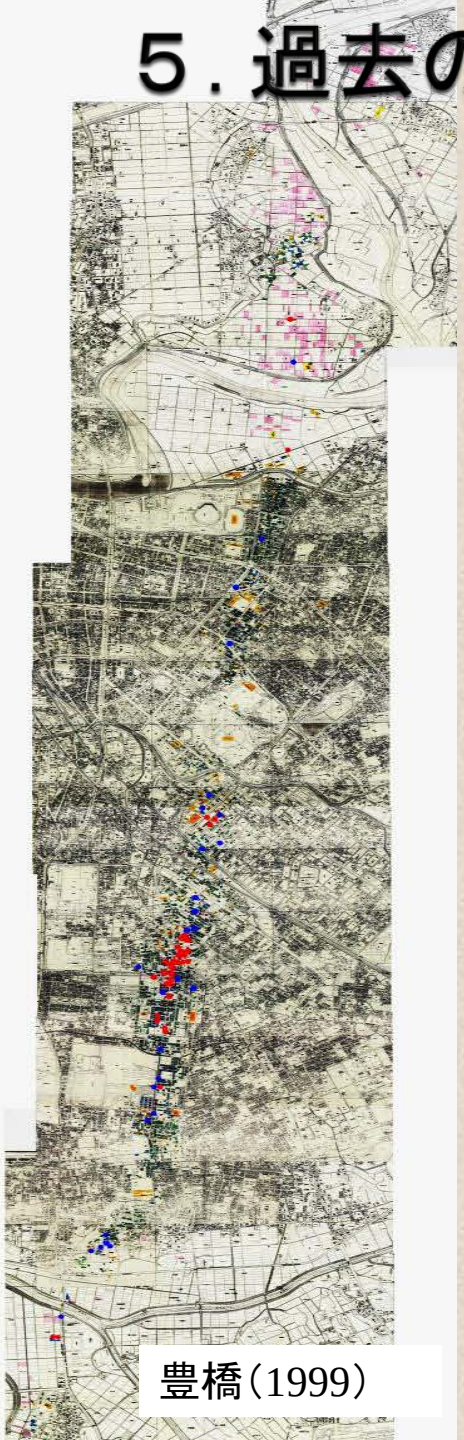
被災後の修復状況＝後藤研究室撮影。

5．過去の被害との比較

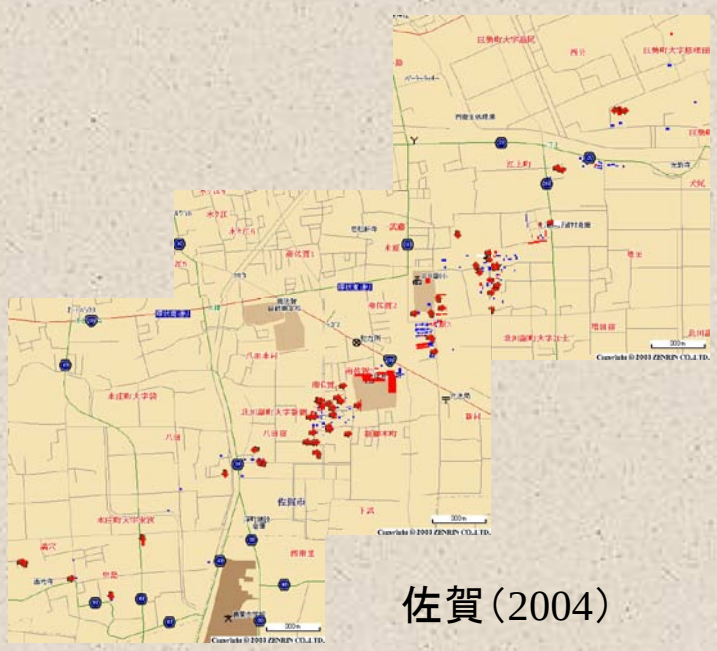
発生日	発生場所	竜巻規模			人的被害［人］		住家被害［棟］		
		フジタスケール	被害域幅[m]	被害域長さ[km]	死亡	負傷	全壊	半壊	一部損壊
1990.12.11	千葉県茂原市	F3	500～1200	6.5	1	73	82	161	1504
1999.9.24	愛知県豊橋市	F3	50～550	18.0	0	415	40	309	1980
2002.7.10	埼玉県深谷市	F2	100～150	4.5	0	11	7	0	87
2004.6.27	佐賀県佐賀市	F2	200～400	8.0	0	15	15	25	305
2005.12.25	山形県酒田市注1)	F1	100	9.0	5	33	0	0	4
2006.9.17	宮崎県延岡市	F2	150～300	7.5	3	143	79	348	753
2006.11.7	北海道佐呂間町	F3	100～300	1.4 (15)	9	31	7	7	25
2009.7.19	岡山県美作市	F2	200	6.0	0	2	2	11	65
2009.7.27	群馬県館林市	F1～F2	50	6.5	0	21	14	24	286
2009.10.8	茨城県土浦市	F1	200～300	2.8	0	2	1	11	94
	茨城県利根町	F1	100～200	6.0	0	4	0	5	116
	千葉県九十九里町	F1	20～30	1.6～1.7	0	0	1	0	36
2011.11.18	鹿児島県徳之島町	F2	100	0.6	3	0	1	0	0
2012.5.6	茨城県常総市・つくば市	F3	500	17	1	37	89	178	384
	茨城県筑西市・桜川市	F1	600	21	0	3	0	1	144
	栃木県真岡市・益子町・茂木町，茨城県常陸大宮市	F1～F2	650	32	0	12	13	35	438
	福島県会津美里町	F0	300	2	0	0	0	0	(不明)

５．過去の被害との比較

茂原（1990）

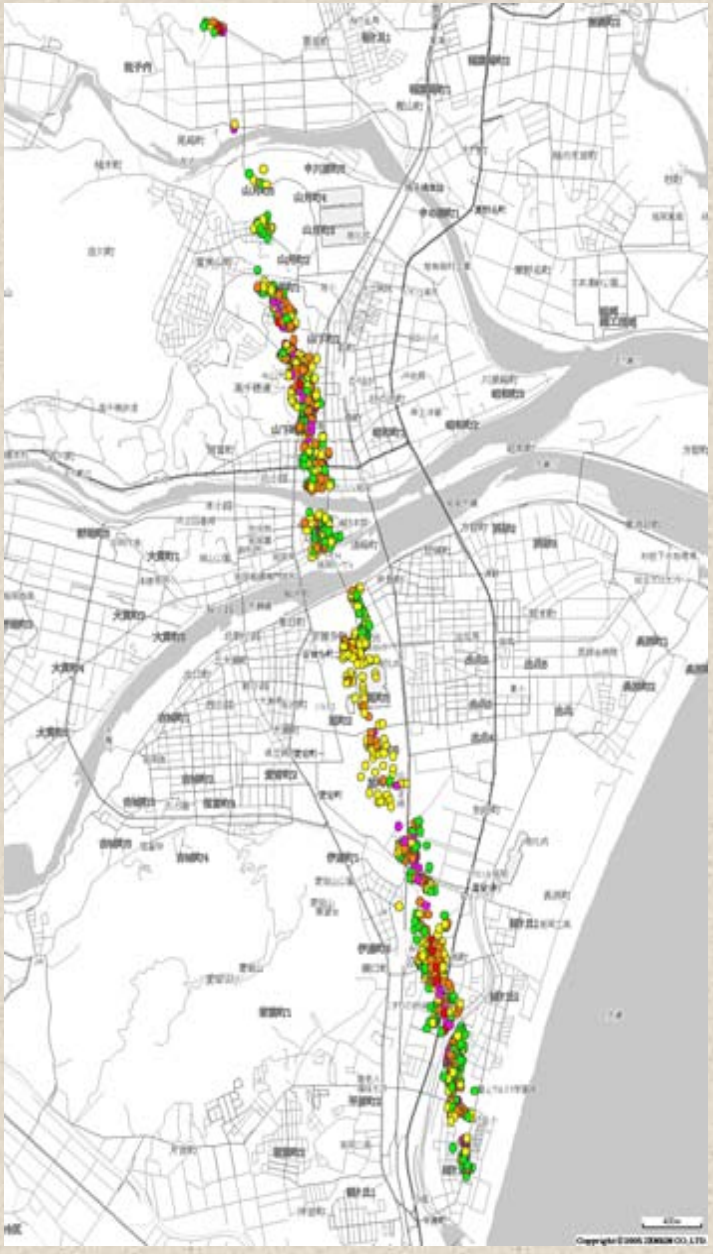


豊橋（1999）

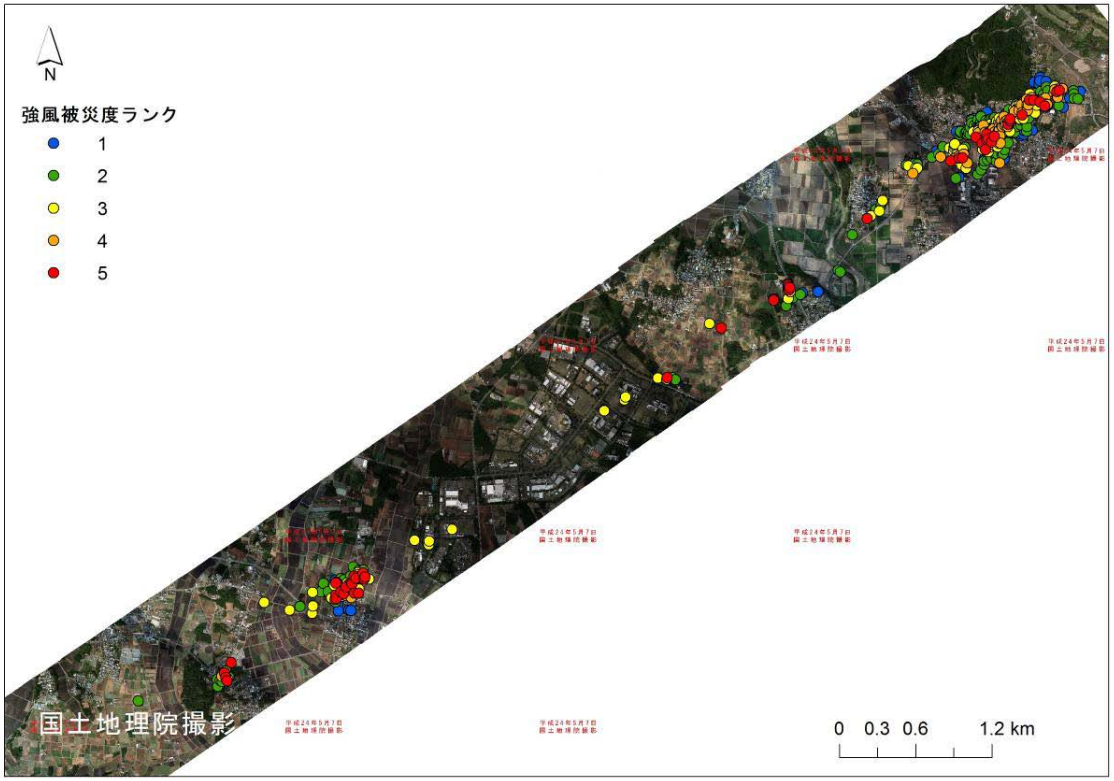


佐賀（2004）

５．過去の被害との比較



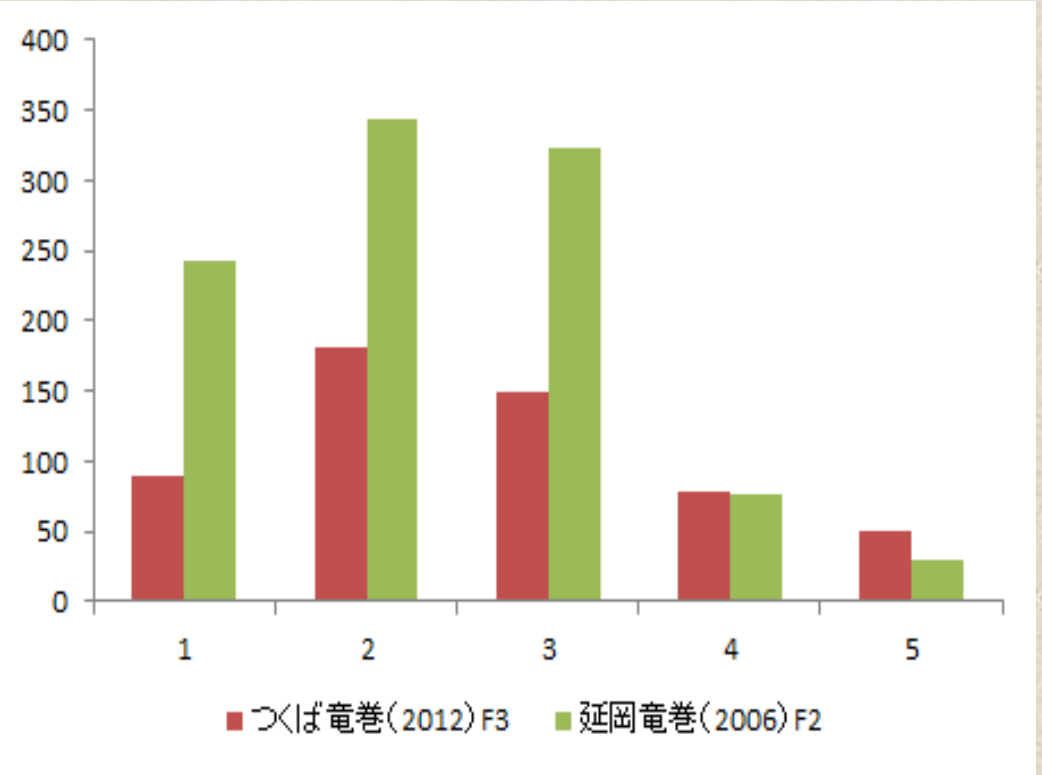
佐呂間（2006）

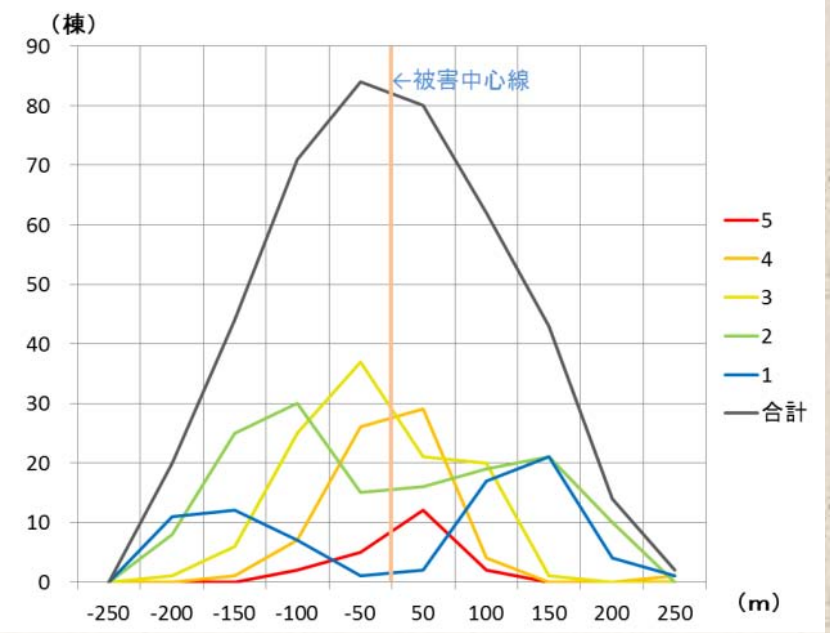


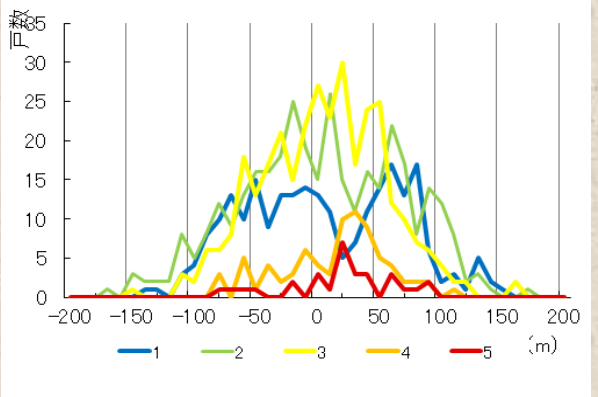
延岡（2006）

つくば（2012）

つくば竜巻と延岡竜巻の被害







- 強風被災度ランクによるつくば竜巻（2012）と延岡竜巻（2006）の被害の比較

被害形態木造建築物

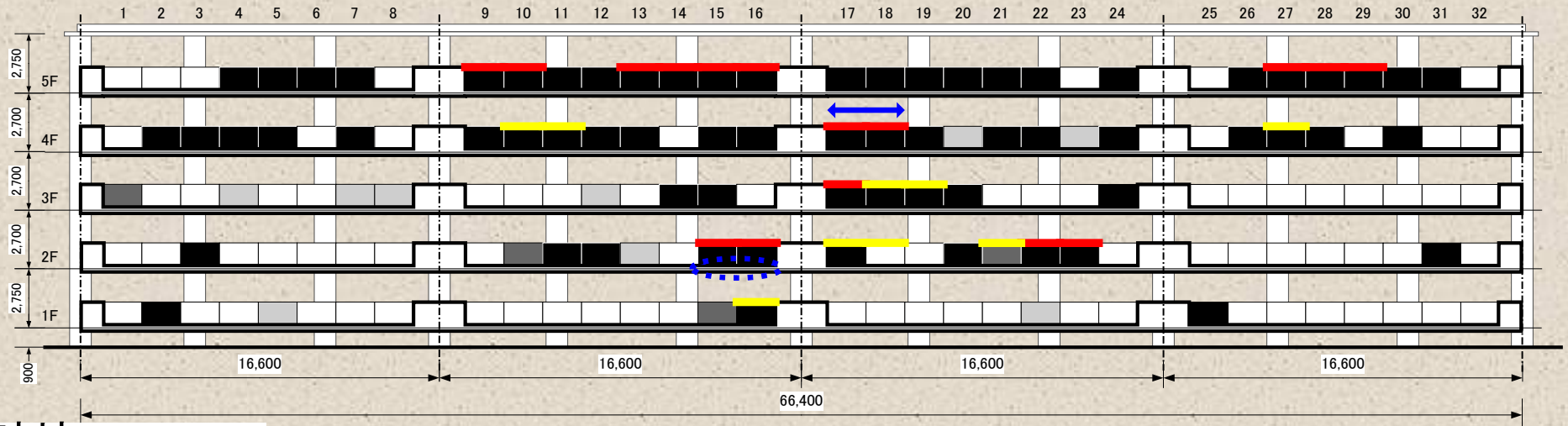
- 転倒・飛散・倒壊
  これまでの竜巻被害では、大きな開口部をもつ店舗、作業所との併用住宅、小規模な事務所で、倒壊、飛散等の被害が見られた。
  　茂原竜巻（1990）では、転倒・倒壊・飛散した建築物は「平面上に比較的大きな柱・壁なしの空間（8～48坪）を有していながら、それに対応した構造的配慮が特にはなかった」。一般的な住宅が倒壊・飛散した事例は報告されていない。
- つくば竜巻では築2年の木造住宅が基礎から転倒した。

枕崎竜巻（1990）

佐呂間竜巻F3（2006）

茂原竜巻F3（1990）

Distribution of Damage to external members



面破壊

い衝突痕

微な衝突痕・亀裂

目隠しパネル

:両側又は片側の支点の離脱

:著しい変形

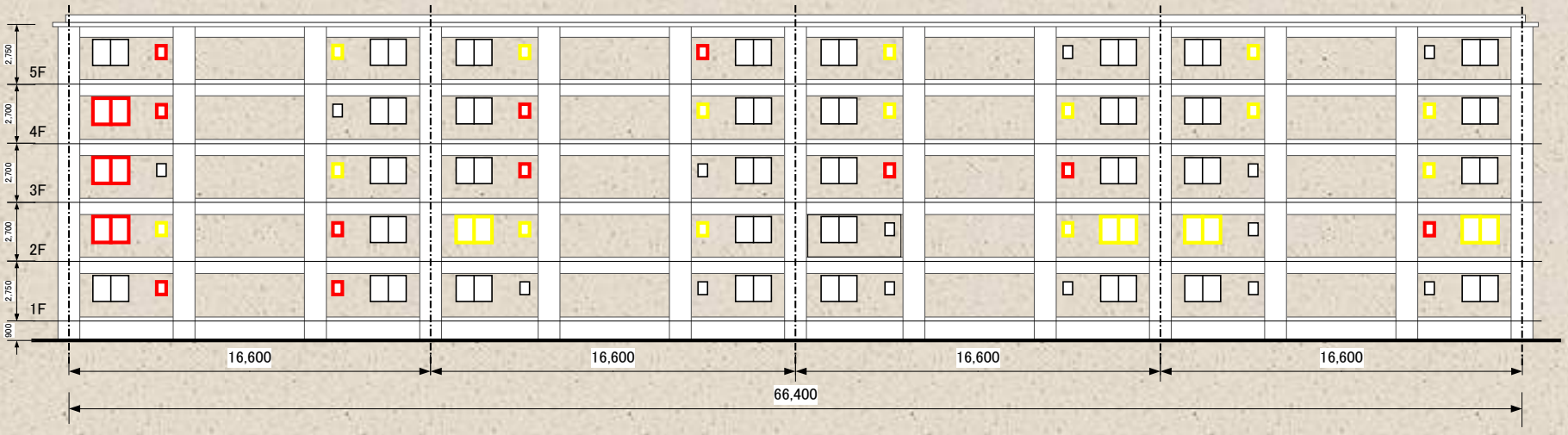
手摺り

建具等の被害分布状況（南面のアルミサッシ）

：サッシの継続使用不可・ガラスのはめ込み不可

：サッシの継続使用不可・ガラスのはめ込み可能

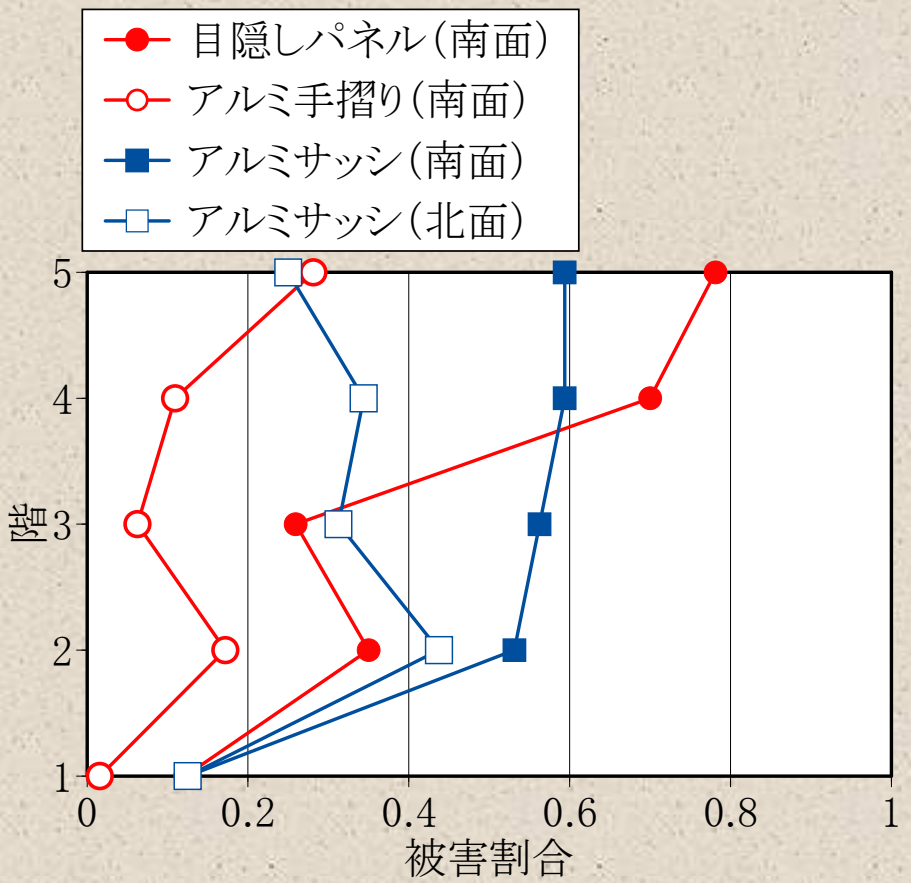
建具等の被害分布状況（北面のアルミサッシ）

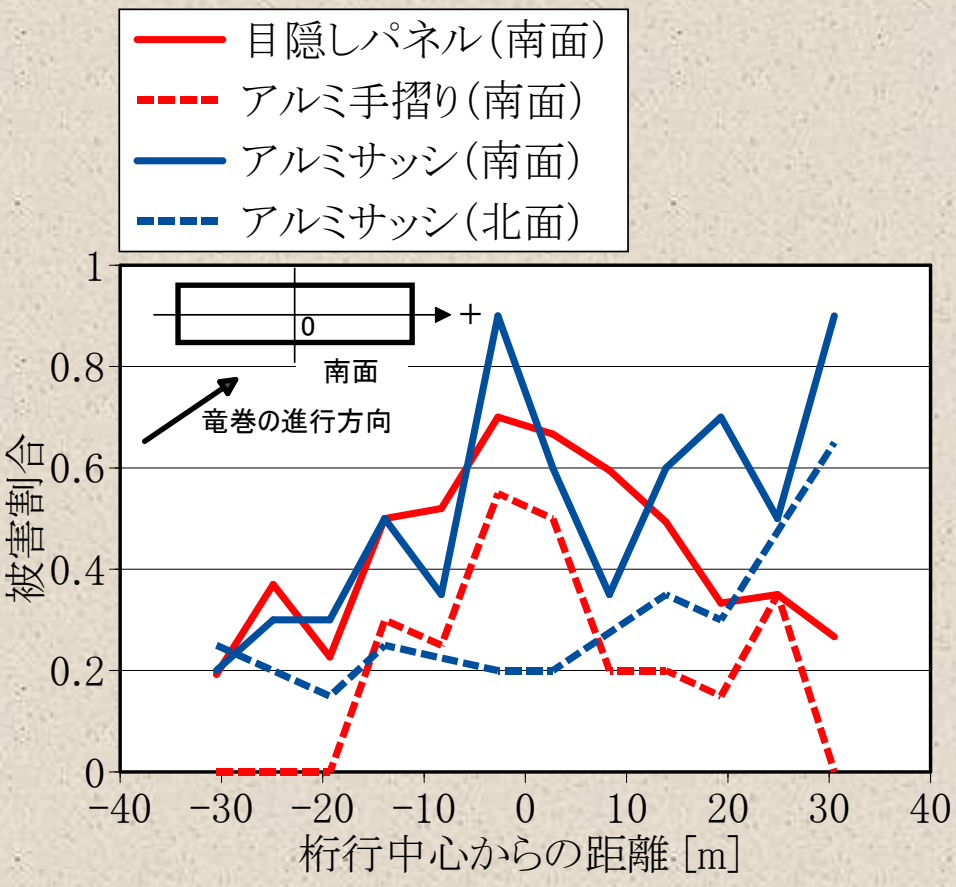


：サッシの継続使用不可・ガラスのはめ込み不可

：サッシの継続使用不可・ガラスのはめ込み可能

被害分布状況に基づく被害割合





- いずれの部位も1階の被害割合が他の階よりも極めて小さく，南面では上階になるにつれて甚大な被害範囲が大きくなる傾向が認められる。ただし，目隠しパネルとアルミ手摺りは2階の被害割合が3階よりも大きく，これは飛来物による衝突の多寡が影響している可能性がある。
- 南面の部位では，桁行中心付近で被害割合が高い傾向が認められる。

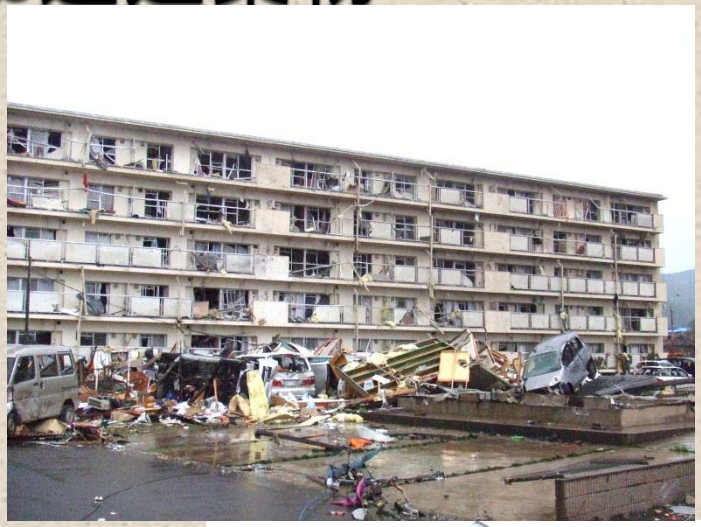
RC造建築物・S造建築物

- 工学的に設計・施工された建築物の非構造部材（外装材・内装材等）の被害

  集合住宅・事務所・学校建築物・工場など

- 学校建築物に直撃
  豊橋（1999）、佐賀（2004）、真岡（2012）など

  建築基準法での扱い



4. 建築物等の被害から推定される風速

A) 風圧力

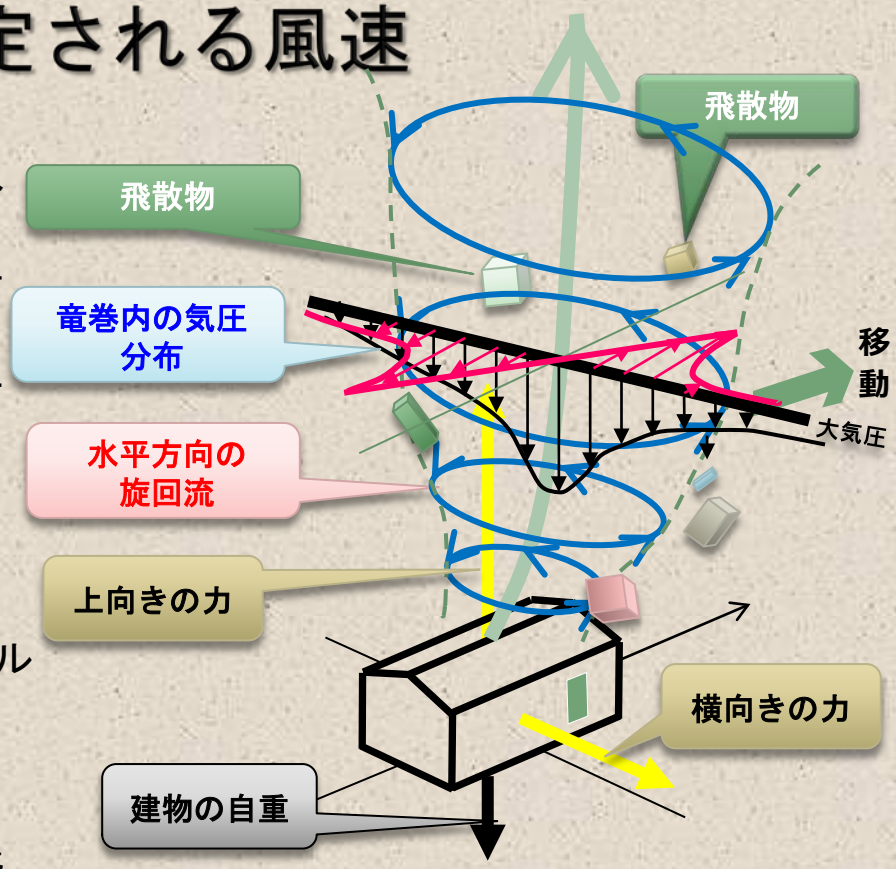
- 竜巻の旋回流の水平方向と鉛直方向の速度成分
- 地表面付近では水平方向の速度成分が卓越する
- 建物全体を水平方向に押すだけでなく、屋根面には負圧も発生する。
- 開口部や外壁が破損し、建築物の内圧が上昇することもある。

B) 気圧差（竜巻の中心付近）

- 竜巻渦内の低い気圧と大気圧との差
- 竜巻をランキン渦と仮定する[2)]と、藤田スケールと気圧降下量には右下の関係がある

C) 飛来物

- 建築物等の部材・什器・樹木・車両などが建築物の外皮に衝突し、場合によっては貫通する



藤田スケール	中心での気圧降下(kN/m²)	最大風速半径での気圧降下(kN/m²)
F0	- 1.2	- 0.6
F1	1.2 - 2.8	0.6 - 1.4
F2	3.0 – 5.6	1.5 - 2.8
F3	5.8 – 10.2	2.9 - 5.1
F4	10.4 – 16.2	5.2 - 8.1
F5	16.4 – 24.0	8.2 - 12.0

1) 室田・山口・鈴木・新野・藤谷:1990年の千葉県茂原市の竜巻による建築物の被害調査報告、建築研究資料No.78,1992.3から一部引用
2) J.Lee, T.Samaras, C.Young: Pressure Measurement at the Ground in an F-4Tornado, 22nd Conference on Severe Local Storms,2004