災に寄与する Web サイト構築のため、外国人への防災教育普及のための防災イベントを 2017 年 3 月に企画した。この企画を通じて、外国人を対象とした防災対策をすすめていく上での新たな防災ネットワークを構築した。これにより、東三河地域で生活する外国人を含んだ防災教育の場の提供が実現できるようになった（写真 3-8）。今後はこうした場において、より詳細に外国人対応のあり方を検討していきたい。

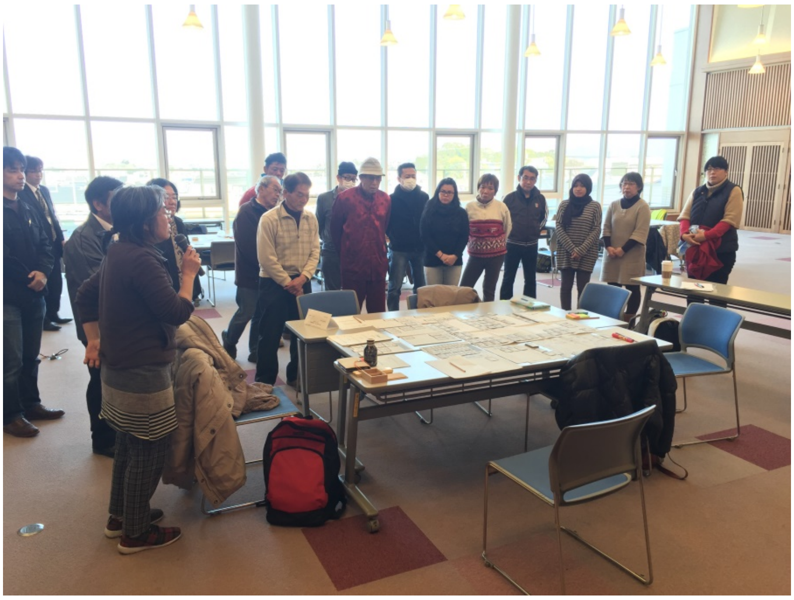


写真 3-8　新しい防災ネットワークによる外国人を含んだ防災教育の場の提供（2018/1）

4 Web サイト「つながる防災」の有効性の検討

4.1「つながる防災」を通じて発信された記事

表 4-1 Web サイト「つながる防災」を通じて発信された記事一覧（2016/4-2018/2）

■…情報提供、情報発信支援
◎…メディア掲載情報
☆…自主企画

4月

■2016/04/04 H28 年度「とよはし防災リーダー養成講座」受講者募集（申込締切 4.22） （127views）
■2016/04/04 明海地区防災連絡協議会の活動が NHK「ほっとイブニング」で紹介されます！ （52views）
☆2016/04/15［コラム］熊本の地震被害を受けて（斉藤大樹） （280views）
■2016/04/26 豊橋市からのお知らせ：「豊橋ほっとメール」と「豊橋防災ラジオ」 （99views）

5月

◎2016/04/26［メディア掲載］斉藤大樹「南海トラフに目を」（東愛知新聞 4/22） （82views）
◎2016/05/07［メディア掲載］「防災センサー開発を計画」／「防災情報共有効果的ツール」（東愛知新聞 5/3、5/7） （73views）
◎2016/05/11［メディア掲載］「熊本地震の教訓 東三河に生かす」（東愛知新聞 5/11） （91views）
☆2016/05/12 熊本地震調査結果（速報）＆報告会 ※ 終了しました （714views）
◎2016/05/13［メディア掲載］「車中避難者想定した訓練必要」（東愛知新聞 5/13） （58views）
◎2016/05/13［メディア掲載］「避難所外の生活支援体制重要」（東日新聞 5/13） （50views）
■2016/05/15 シンポジウム「熊本地震が警告する南海トラフ巨大地震対策の盲点」（5/14 名古屋工業大学）※終了しました （173views）
☆2016/05/17［報告］平成２８年度 御津臨海企業懇話会が定期総会・研修会を開催（5/13） （66views）
◎2016/05/17［メディア掲載］「牛久保地区（豊川市）防災まち歩きマップ完成」（東日新聞 5/17） （72views）
◎2016/05/24［メディア掲載］「豊橋技科大で熊本地震被害調査報告会」（文教速報 5/23） （78views）
◎2016/05/25［メディア掲載］「熊本地震の課題検証ＷＧ発足」（東日新聞／東愛知新聞 5/25） （211views）
◎2016/05/30 エフエム豊橋「天伯之城 ギカダイ」に豊橋技術科学大学 斉藤大樹教授が出演します（放送予定日 6/4） （37views）

6月

■2016/05/31 中部経済産業局より地域連携 BCP の取組紹介がありました （72views）
■2016/06/10［参加者募集］「避難所運営ゲーム HUG」を用いた災害対策研修会のご案内（7/9 豊橋） （96views）
■2016/06/10［参加者募集］救急法救急員養成講習会のご案内（7/17,24,31 豊橋） （70views）
◎2016/06/17［メディア掲載］「地域防災力評価にツール活用」（東愛知新聞 6/17）他 1 件 （61views）
◎2016/06/20［メディア掲載］「豊橋市強靭化計画初会合」（中日新聞 6/18） （62views）
■2016/06/22［ご案内］海フェスタ東三河防災セミナー（7/24 豊橋） （103views）

7月

■2016/06/24［ご案内］減災連携研究センターシンポジウム「熊本地震に学び、今後に備える！」（6/30 名古屋） （113views）
☆2016/07/07 平成 28 年熊本地震災害調査報告書（土構造物及び自然斜面の被害） （94views）

9月

◎2016/07/28［メディア掲載］「とよしん栄会のセミナーで技科大斎藤教授が講演」（東日新聞 7/28） （60views）
■2016/09/05 蒲郡信用金庫、蒲郡市と帰宅困難者受け入れについて防災協定 （45views）
■2016/09/05 御津臨海企業懇話会、臨港道路東三河臨海線の早期整備等に関する要望書を豊川市に提出 （57views）
■2016/09/06 主要地方道飯田富山佐久間線、佐久間ダムから熊打橋まで崩土・倒木により通行止め （60views）
☆2016/09/06 10 月 5 日（水）開校「東三河防災カレッジ ～あしたにつながる防災の知識と実践力～」参加者募集は 9 月 30 日まで （493views）
■2016/09/07 豊橋市、防災マップのタガログ語版／英語版を公開 （59views）
…Toyohashi City has released the Tagalog and English versions of the Evacuation Map
■2016/09/07 豊橋市と市内のバス会社 3 社「災害時におけるバス利用に関する協定」を締結 （48views）
■2016/09/08 三河湾沿岸などの 13 市町にて「南海トラフ巨大地震に備える」をテーマにパネル展開催 （50views）
■2016/09/08 平成 28 年度豊橋市総合防災訓練、実施 （135views）
■2016/09/09 9 月 25 日（日）、「2016 しんしろ消防防災フェスタ」開催 （91views）
■2016/09/13 田原で消防などによる水難救助合同訓練実施 （46views）
■2016/09/14 愛知教育大、危機管理セミナー「あの時何が起こったか～熊本地震から振り返る地域防災と大学～」を 9 月 28 日開催 （63views）

10月

■2016/09/14 平成 28 年防災功労者防災担当大臣表彰、豊橋防災ボランティアコーディネーターの会 （69views）
☆2016/10/03 10 月 5 日（水）に開校「東三河防災カレッジ ～あしたにつながる防災の知識と実践力～」追加募集開始！（131views）
☆2016/10/03 小野高宏氏（三菱商事インシュアランス）講演タイトルが『企業の事業継続計画とマネジメント』に決定 （109views）
☆2016/10/21 平成 28 年度防災シンポジウム「熊本地震から学ぶ震災後の復興 - 生活レジリエンスと事業レジリエンス -」 （302views）

11月

■2016/10/25 地盤工学会が主催する三河地方の防災に関するシンポジウム、11 月 21 日開催 （118views）
◎2016/11/01［メディア掲載］豊川「牛久保安心・安全なまちづくり協議会」で辛島先生が解説（10 月 26 日付 東愛知新聞 11 面） （60views）
■2016/11/02 豊川市防災講演会「頻発する風水害の事例に学ぶ」参加者募集（12 月 17 日開催） （100views）
◎2016/11/09［メディア掲載］「東三河防災カレッジ 地域課題探求ツアー」（平成 28 年 11 月 05 日付 中日新聞東三河版） （71views）
◎2016/11/28［メディア掲載］「防災シンポジウム 熊本地震から学ぶ震災後の復興 - 生活レジリエンスと事業レジリエンス -」 （62views）
（平成 28 年 11 月 20 日付 東日新聞 3 面）

12月

1月

☆2016/12/26 平成 28 年度防災シンポジウム、盛況のうちに終了！ （33views）
■2017/01/12 豊橋防災ラジオ保守点検作業に伴い、1 月 27 日 14 時から 17 時まで運用停止（情報提供） （10views）
■2017/01/13「避難準備情報」を「避難準備・高齢者等避難開始」に名称変更（情報提供） （18views）
☆2017/01/18 外国人向け体験型防災講座「多文化のまちで暮らす 豊橋の防災」3 月 11 日開催決定（自主企画） （109views）
■2017/01/25 2 月 26 日「平成 28 年度田原市防災講演会」開催（情報提供） （20views）
■2017/01/27 1 月 28 日「平成 28 年度蒲郡市防災セミナー」開催 （24views）

（平成 29 年 1 月末日現在）

■…情報提供、情報発信支援
◎…メディア掲載情報
☆…自主企画

5月

6月

■2017/05/08 H29 年度「とよはし防災リーダー養成講座」受講者募集 (41views)
◎2017/06/05 [メディア掲載]「建物耐震診断 システム化」（日刊工業新聞 5/23） (28views)
◎2017/06/05 [メディア掲載]「８国立大 地震時連携へ」（読売新聞 5/25） (26views)
☆2017/06/05 [報告] 御津臨海企業懇話会が「平成２９年度定期総会・第１０回研修会」を開催 (29views)

7月

☆2017/06/05 愛知大学三遠南信地域連携研究センターの共同研究課題として採択 (34views)

8月

■2017/07/18 多文化防災ネットワーク愛知・名古屋主催の防災イベント(7/23 豊橋、8/20 名古屋) (57views)
☆2017/08/03 10月3日(火)開校「東三河防災カレッジ」受講生募集は9月29日まで (331views)

9月

■2017/08/08 [報告]御津臨海企業懇話会が「平成２９年度第１回防災作業部会（地域連携ＢＣＰ策定）」を開催 (67views)
■2017/09/12 2017年度自然災害リスクセミナーが開催(11/2) (申込締切10/10) (28views)
☆2017/09/19 「東三河防災カレッジ」全日程が決定＆申込受付中 (83views)
■2017/09/28 愛知県が主催する「みずから守るプログラム　シンポジウム」10月13日開催 (17views)

10月

☆2017/09/28 H29年度「東三河防災カレッジ」の受講生募集期間を延長します。 (83views)
☆2017/10/13 豊橋技術科学大学プロジェクト研究成果報告会（10/26 豊橋） (19views)
☆2017/10/17 講義の延期開催のお知らせ (39views)
■2017/10/25 [報告]御津臨海企業懇話会が平成２９年度第２回・第３回防災作業部会（合同防災訓練の検討）を開催 (28views)
☆2017/10/26 [ご案内]豊橋技術科学大学防災シンポジウム2017の開催について (133views)

11月

☆2017/10/27 H29年度豊橋技術科学大学 総合防災訓練を実施 (32views)
☆2017/11/06 山間集落支援：集落のお祭りを次の世代へ（10/22 新城） (65views)

12月

☆2017/11/08 山間集落支援：たくさんの人とのかかわりでつくる（新城） (74views)
■2017/12/18 [報告]御津臨海企業懇話会が「平成２９年度御津臨海企業懇話会合同防災訓練」を実施 (9views)
☆2017/12/21 東海圏減災研究コンソーシアム・防災シンポジウム（3/24 豊橋） (52views)

1月

☆2017/12/28 チラシが完成しました｜東海圏減災研究コンソーシアム・防災シンポジウム（3/24 豊橋） (53views)
■2018/01/09 [報告] 平成２９年度三河港振興会蒲郡地区委員会防災部会総会・基調講演を開催 (18views)
☆2018/01/12 専用応募フォームが完成しました｜東海圏減災研究コンソーシアム・防災シンポジウム（３／２４豊橋） (15views)

2月

☆2018/01/22 ご案内：越境地域政策研究フォーラム（2/10 豊橋） (10views)
☆2018/02/02 日本建築学会メキシコ中部の地震災害調査団速報会（2/16 東京） (24views)

（平成 30年 2 月末日現在）

4.2 記事別閲覧数にみる効果

Web サイト「つながる防災」を通じて発信された記事一覧（2016/4-2018/2）を、その内容から「情報提供、情報発信支援」、「メディア掲載情報」、「自主企画」に分類して整理した（表 4-1）。また、情報種別と閲覧数との関係をみるため、アクセスカウンターの閲覧数を記事ごとに整理し、それをグラフ化した（図 4-1）。

これをみると、「☆熊本地震調査結果（速報）＆報告会」、2016 年度と 2017 年度に実施した「☆東三河防災カレッジ」・「☆防災シンポジウム」などの自主企画イベントは、他の記事よりも総じて閲覧数が多い。ちらし配布や広報誌への情報掲載等、他メディアでの広報も行う「自主企画」の取組は、他の「情報提供、情報発信支援」記事よりもアクセス数が多い傾向にある。また、記事掲載の頻度が高くなると、その直後の記事のアクセス数も増える傾向にある。

Web サイト「つながる防災」は、「情報提供、情報発信支援」を通じて取組格差や情報格差の解消に寄与する目的と「自主企画」の防災イベントを通じて防災意識啓発、ネットワーク構築等に寄与する目的で情報発信を行っているが、今回のアクセスカウンターの記録を通じて、情報の質

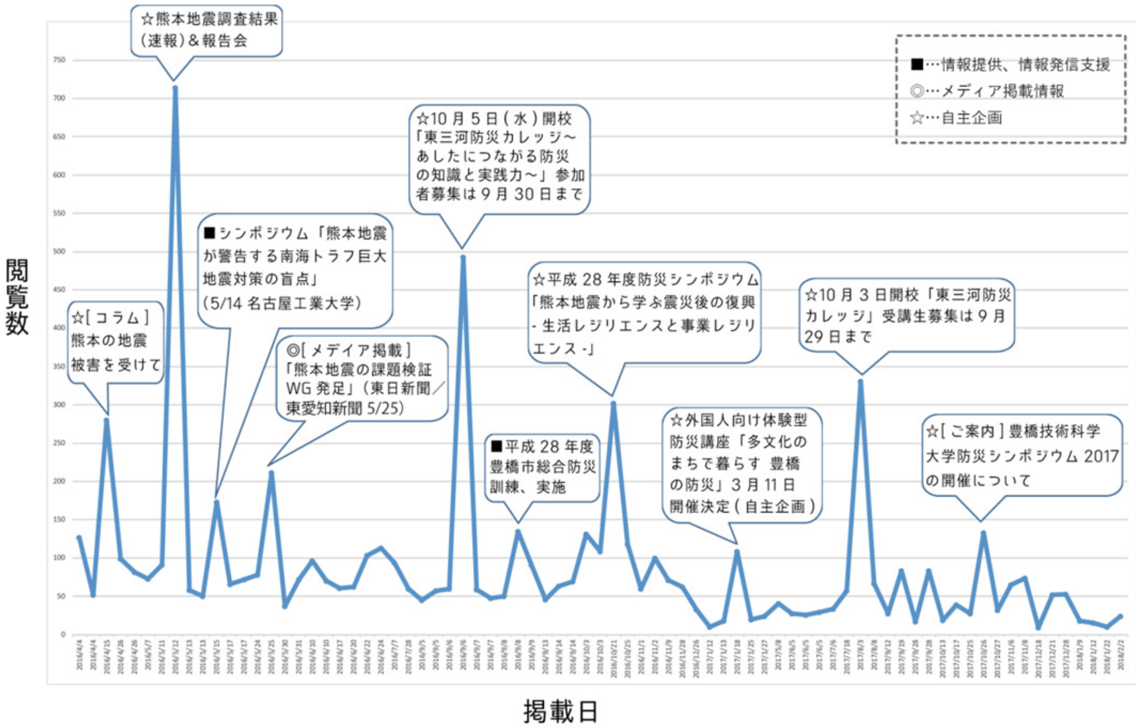


図 4-1　記事と閲覧数との関係

が確保されていることは当然のことながらそれとは別に、Web サイト閲覧者を増やすためには、その他メディアを通じた情報発信と当 Web サイトとの関連付け、そして記事掲載の頻度を高めることが重要であることがわかった。

4.3 防災教育教材提供サービスの整備・公開

平成 27 年度までの Web サイトの利用者は工業団地の企業等を想定していたが、今年度からは Web サイトの内容拡充を検討し利用者の拡大を図った。2016 年 4 月に発生した熊本地震の調査速報を「つながる防災」に掲載したことで Web サイトの閲覧者が増加したことを受け、「つながる防災」の機能拡充を行った。

また、本研究助成における外国人を対象とした情報提供のあり方に関する調査や防災教育イベントの実施結果を踏まえ、SNS による情報提供の他、外国語翻訳した防災教育教材の提供について次のように検討した。

【SNS との関連付け】

本研究で把握した外国人が友人知人との交流を図る他、生活に必要な情報を得るために広く SNS を利活用している状況を踏まえ、「つながる防災」の情報発信機能を増やし、ソーシャル・ネットワーク・サービス（SNS）との関連付けを行った。「つながる防災」に掲載された記事情報

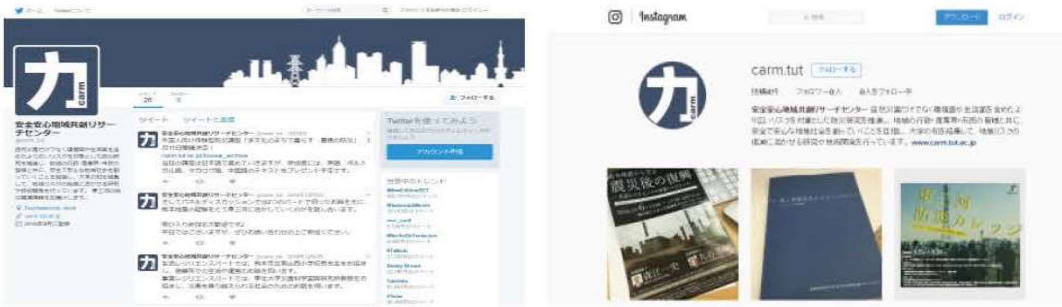


図 4-2　「つながる防災」の SNS との関連づけ

図 4-3　防災教育教材を提供する「つながる教材」ページ

(http://carm.tut.ac.jp/bousai_archives/textbook)

をシェアして Facebook、Twitter、Instagram 等の SNS のタイムライン上にも掲載することで「つながる防災」へのアクセス経路の改善を図った（図 4-2）。

【防災教育教材を提供する「つながる教材」】

また、Web サイト「つながる防災」の機能のひとつとして、新たに様々なニーズに即して防災教育教材を提供する「つながる教材」と名付けたページを設置した（図 4-3）。これまでに防災教育プログラムとして開発したテキストの一部を誰もが自由にダウンロードして使えるよう公開した他、多言語対応した防災教育テキスト（※）、防災に関する講演動画、2.3 にみた海外事例の調査結果などもあわせて公開し、大学の知の普及を図った。

※多言語翻訳したテキスト（一部）は、参考として本報告書の資料編に掲載した。

5　成果のまとめ

5.1 得られた成果

本書冒頭にあげた５つの研究課題に即して、本研究テーマへの取り組みによって得られた成果を述べる。

1）学校や地域の防災啓蒙・知識の普及に役立つ講義・教材等を Web サイトで公開し、大学の知の普及を図る。

東三河地域で生活する日本人のみならず、外国人の防災啓蒙と地域の普及にも役に立つよう、多言語翻訳化した防災教育用テキストを作成し、Web サイト「つながる防災」上に設置した「つながる教材」での公開をスタートした。また、視覚聴覚で学ぶ教材として、本学が主体的に実施する「東三河防災カレッジ」の講義動画や防災シンポジウムの講演動画の公開もスタートした。
（関連章：4 章）

2）東三河地域に住む外国人の防災ニーズを把握し、必要な情報を提供する外国語 Web サイトを構築する。

過去の災害発生時には、災害に対する理解や正しい知識がないために、冷静な対応をとることができない外国人が多くみられたことから、外国人向けの防災に関する情報提供や教育はこの東三河地域においても重要な課題となっている。本研究では、Web サイト「つながる防災」を、外国人を対象とした防災対策に活用することも視野に入れた基礎的な調査を行った。

その結果、近年の SNS の普及にともない、平時災害時問わず SNS は外国人への情報提供上重要なツールであることを確認した。一方、外国人の防災意識啓発・教育という点では、全国各地でさまざまなツール開発を行っているものの未だ適切な情報提供ツールがないことを確認した。

この東三河地域の外国人を雇用している企業では、言語対応が困難であるという理由などから、必ずしも日本人と同様の防災教育を行えていない現状があり、防災教育の場の提供が必要であることを把握した。そして以上の点を踏まえ、多言語翻訳した教材の作成・公開や Web サイトの SNS 対応等を行った。
（関連章：2 章、4 章）

3）Web サイトを通じた様々な防災情報の発信、防災イベント等を企画する。

防災に関わる人材の育成を行う「東三河防災カレッジ」の他、防災シンポジウムや研究調査報告会など、防災意識啓発、知の普及活動を行った。また、課題 2）との関連から、東三河地域の外国人市民も対象とした防災教育の場の提供も行った。その際、外国人市民の地域での暮らし方がリーマン・ショック前後に大きく変化し、これに対応した外国人防災のあり方を検討する必要があることを把握すると同時に、災害への危機意識をもった外国人市民が増加しており、災害弱

者としてではなく災害時に他の外国人市民を支え得る高い防災意識をもった頼もしい外国人の存在も把握した。
（関連章：3章）

4）大学・企業・自治体・市民をつないだ防災ネットワークを構築する。

上記に関連し、外国人の生活支援や防災対応を行う行政担当課、国際交流団体、学校教育施設運営者等と新たにネットワークを構築した。これにより、災害弱者とみなされがちな外国人を含んだ市民の自助・共助の力を促進する機会が増え、そのための情報提供等のツール開発が大きく前進した。
（関連章：3章）

5）Web サイトを通じた防災コミュニティ形成の在り方を探る。

Web サイト「つながる防災」では、「情報提供、情報発信支援」を通じて取組格差や情報格差の解消に寄与する目的と、本学の「自主企画」の防災イベントを通じて防災意識啓発、ネットワーク構築等に寄与する目的で情報発信を行った。その結果、情報を単に集約する場としてだけなく、防災啓発、知の普及を図る活動と連動した利用の場とすることで、よりよいコミュニティ形成につながることが確認できた。
（関連章：4章）

5.2 Web サイトを通じた防災コミュニティ形成の可能性

以上の成果から、今回の Web サイト「つながる防災」のような Web サイトを利用して情報の集約・発信を行う場合、さまざまな場所で公開されている情報をひろい集め、それらをみんなで広く共有できるようにするやり方は、一見「情報のひろば」のようなものとして、ネットワークづくりに寄与するかのようにみえるが、実際のコミュニティ形成とは全く異なるものであることが実証的な取り組みから把握された。

Web サイトによる情報の集約・発信は、情報を右から左に流すのではなく、あくまで一次情報を中心に取り扱う場であるという認識のもとで運用しなければ、ツールは十分に機能しないだろう。そして一次情報を中心に発信していくためには、一次情報を生む実際の地域コミュニティを相手にした防災活動を絶やさず行うことが重要である。それを持続的に行っていくことによって、それまでに見なかった多様なアクターと結びつき、新たな活動が生成され、災害を克服しうる重層的なコミュニティが形成されていくのだ。Web サイトを通じた防災コミュニティ形成の可能性はそこにあるといってよいだろう。

資料編

目　次

資料編では、外国人の防災教育として、教材翻訳した下記４科目のテキストを添付します。

※この教材については、日本語、英語の他に３か国（中国語・ポルトガル語・タガログ語）に対応。Webサイト「つながる防災」上に設置する「つながる教材」で公開しています
（http://carm.tut.ac.jp/bousai_archives/textbook）

English

つながる教材

斉藤大樹
安全安心地域共創リサーチセンター長

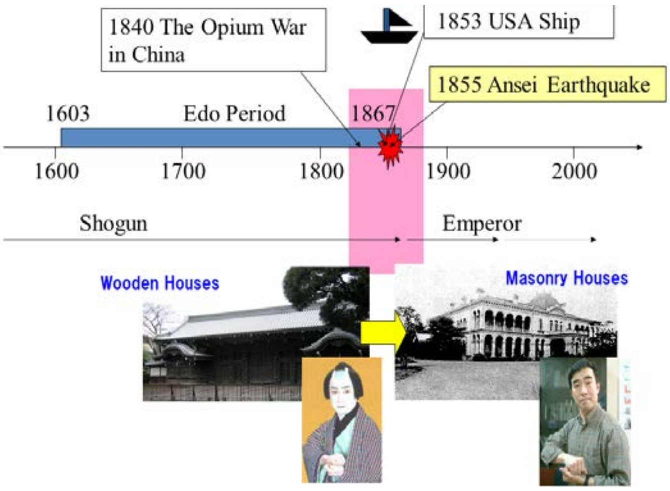
Introduction of Earthquake Safety

Taiki SAITO
Professor, Dr. of Engeering
Toyohashi University of Technology, Japan

Why earthquake happens?

Let's look back on the history of Japan. At the end of the Edo period, Western countries came to colonize Asia. In 1840, Opium war broke out between China and the UK. In 1853 American Matthew Calbraith Perry of America came to Japan boarding on a black ship. At that time, Great Ansei Earthquake occurred. Eventually Edo Shogunate was destroyed. Japan was forced to open the country to foreigners.

In order to catch up with western countries, Japanese traditional wooden houses have been replaced by Western style brick buildings. Topknot and clothing are also changed to Western style.



In that time in Japan, there was a common superstition that earthquake occurs because of Catfish living underground. People used to believe if you put a Nishiki-e (Wood block painting) of Catfish at home, that home would not be crushed by an Earthquake. In this catfish picture, God puts a big stone called 'key stone' on the head of the catfish and holds on to it so that it can't cause earthquake.

Where is Key Stone?

Key stone is enshrined in the premise of Kashima Shrine in Ibaraki prefecture. You can see the stone head about 10 cm on the ground above. Legend says- Shogun ordered his servants to dig the soil for 7 days but even after that they could not reach the bottom of the stone.

The first scientific analysis of the earthquake mechanism is done by German scientist Alfred Wegener.

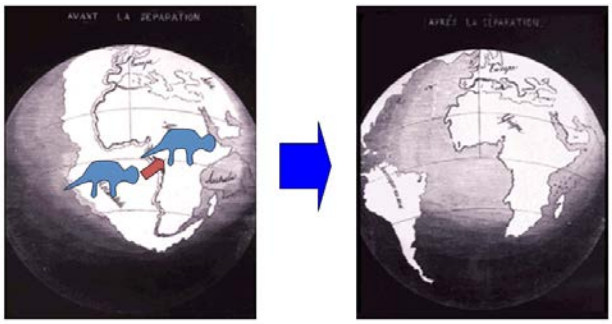
He noticed that the terrain of South America's east matches the shape of the terrain of Africa's west like a Jigsaw puzzle.

He thought that the two continents that are presently far apart were connected in the past. He presented it as continental movement theory at the conference, but from the scientists he was accused of lying. He believed that there must be traces of animals moved from continent to continent, if the continents were connected and for that he examined fossils.

Story of uncle Wegener

Alfred Lothar Wegener (1880-1930)

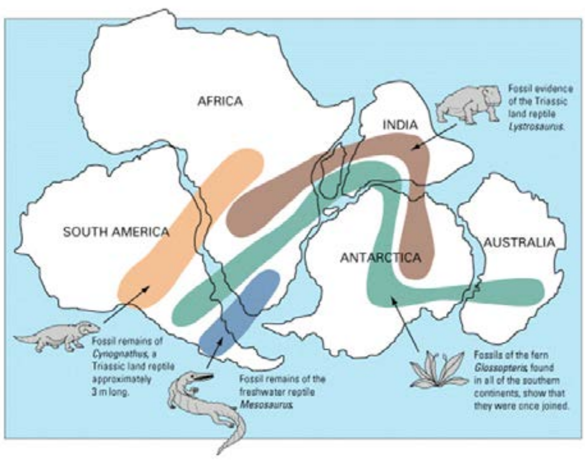
Long time ago　　Present



Liar !!

Then apparently the fossils of the same animal were found on different continents. He thought that was the evidence that the continents were connected. But other scholars didn't agree with him.

Location of fossil



Because among the scholars of that time there was a belief that there was a presence of phantom continent in the present sea location and that all continents were connected. You must have heard of the legend of the phantom continent that is said to exist in the ocean, such as Atlantis Continent (Atlantic Ocean), Mu Continent (Pacific Ocean), Lemuria Continent (Indian Ocean) and so on. As a scientific explanation - because of the cooling of the earth, the surface wrinkled. So the land connected to the continent sunk and became sea.

(Theory of Earth Contraction)

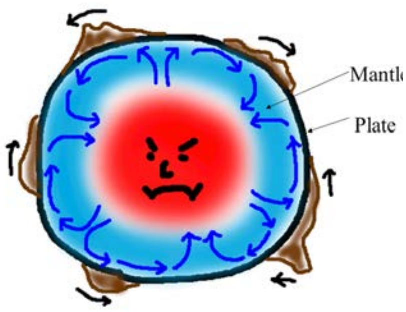
Wrinkles made on the existing land become mountains. This was believed for a long time. This is called the 'Earth Contraction Theory'.
After all, Wegener's continental Contraction theory was too innovative to be admitted that time.

According to Wegener, the attraction of the moon and the centrifugal force due to the rotation of the earth are the driving force for the heavy continents movement. Now we know that the moving of the continent is a convectional phenomenon occurred inside the Earth. Like the heating of cold miso soup, I think you've seen how miso gathered below gets boiled and comes up like volcano eruption and sink down again. If you warm liquid, it gets lighter and goes up and gets cool. Cool liquid is heavier and goes down. It creates a cyclic flow. This process called convection.

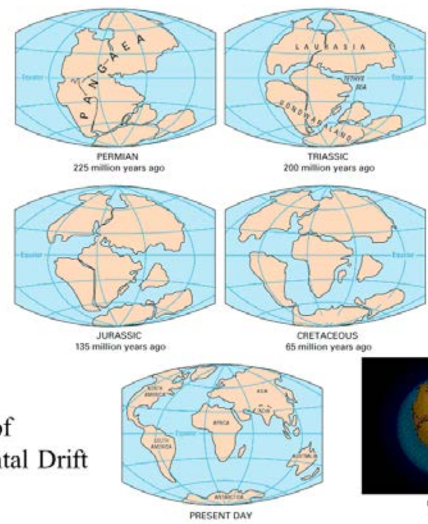
In the center of the earth, there is a mass of iron core at a high temperature , approximately 6000°C and the (outer rock) mantle is believed to be convective like a fluid over a long period of time. Outer side of the mantle, there is a thin rock layer (crust) surrounding the earth. Again, on the upper part of the earth just like a peeled orange, there are also many thin plates loaded with crust. They move at a speed of about several centimeters a year with the mantle convection. So it can be said the mantle convection inside the Earth moves the continents.

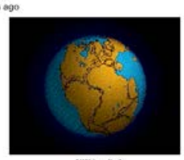
Do you know "convection" ?

Hot ! inside Earth



Wegener believed that there was only one continent on the Earth at the beginning. That got divided and moved to become each current continent. He named the first continent as Pangea, a word derived from Greek meaning for 'all land'. According to plate tectonics, the place where Pangea split corresponds to the current mid-ocean ridge. It's thought that the divided continents will continue repeating the cycle of merging and breaking up in hundreds of millions years to come by.





(Wikipedia)

Theory of Continental Drift (1915)

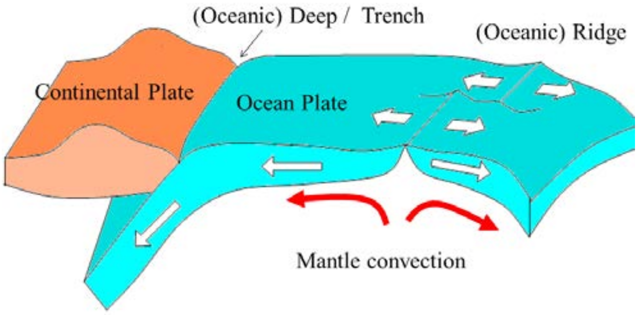
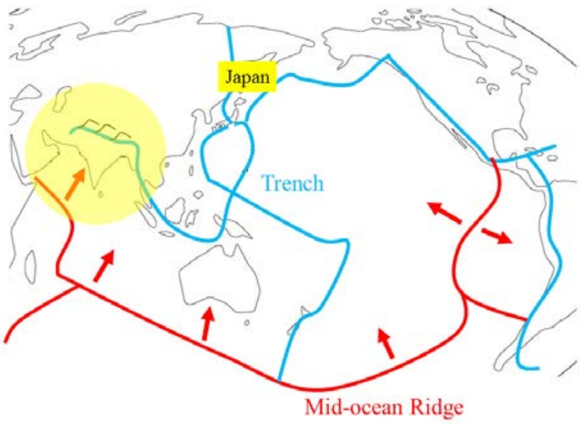


Plate Tectonics

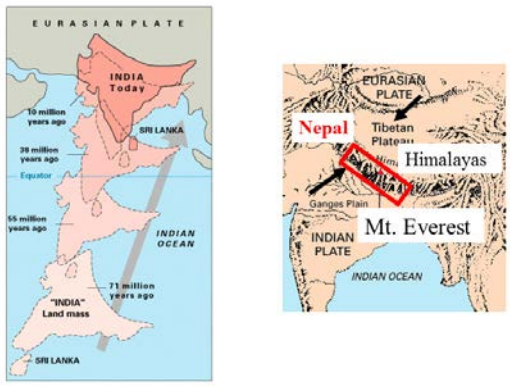
Not only the continents are moving by the mantle convection, but even the ocean above the plate are moving because of it. Continental plates are made of granite with small specific gravity but the oceanic plates are made of large specific gravity basalt. So when these two different form of plates collides, the oceanic plate goes underneath and sinks into the mantle. To compensate for it, on the other side of the subductive plate, new plates are being produced one by one from the cracks of the Ocean floor. The valley at the sea bottom where the plate sinks is called a trench and the mountain range of the ocean floor where a plate is born is called ridge. The theory that explains the movement of plates is called plate tectonics and it is a standard theory of geophysics. Currently, it is possible to accurately measure the movement of plates with satellite.

Off the coast of South America in the East Pacific Ocean, there is a mid ocean ridge that runs north to south. This is where the Pacific plate is born and it is moving northwest at a rate of about 8 cm per year and goes beneath the Eurasian plate. This is a typical example of a continental plate colliding with an oceanic plate.



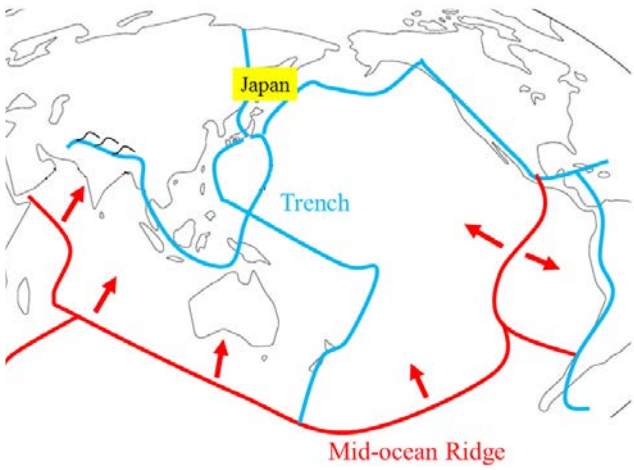
Once India was an independent small continent. By the movement of the plate, it gradually shifted northward and collided with the Eurasian Continent. By that pressure the sea floor got lifted and the present Himalayas were completed. Everest, the world’s highest peak, is also here. In fact, fossil shells were also discovered from the rocks of the Himalayas.

The Himalayas: Two continents collide



There is similar place in Japan too. The Izu Peninsula was an island floating in the ocean. It moved to the north above the Philippine sea plate, collided with the Japanese archipelago and become the Izu Peninsula. It is thought that Tanzawa mountains were made by this pushing force.

In the southern hemisphere of the earth, there are dispersed ridges where plates are born. So many of the plates originated from there move to the north and subduct under another plate. Because many of the ridges are at the bottom of the deep ocean, the eruption activity is suppressed by hydraulic pressure. However, there are places where the ridge is on the surface of the earth.

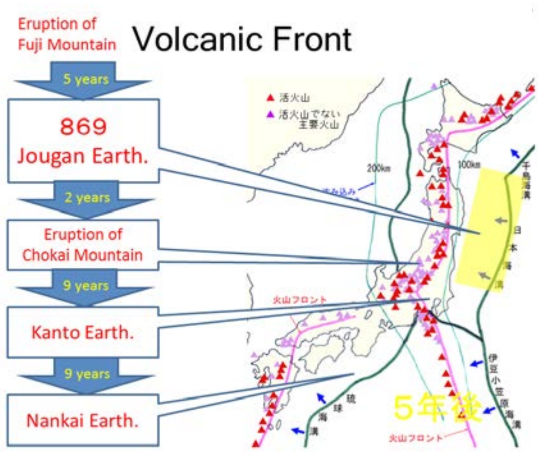


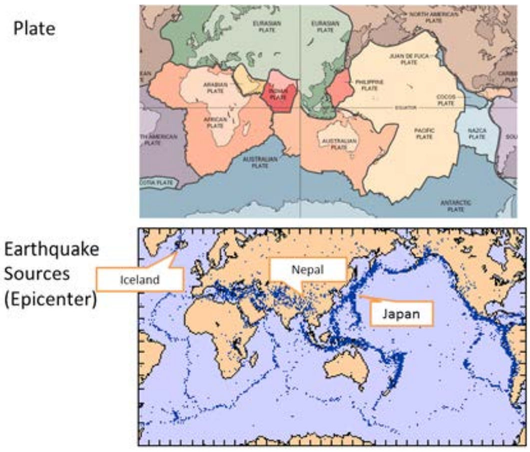
Iceland has a ridge in the middle of the country. So the area of the country gradually increases. Also, because it's a country of volcano, it has world's largest open air bath.

Largest hot spring in the world (Iceland)

Japan is near the trench where plate sinks. Even though it is not a ridge, why are there so many volcanoes? Actually, the subducted plate melts and becomes magma. Then it rises to the surface and becomes volcano. Therefore, the position of the volcano is parallel to the trench where the plate sinks, which is called the volcanic front. After the great east Japan Earthquake of Magnitude 9, Mt. Ontake erupted three years later, Mt. Aso and Mt. Kuchierabujima four years later, and Mt. Sakurajima five years later. Also, in April 2016, an earthquake of Magnitude 7 occurred in Kumamoto prefecture. It seems that along with mega earthquake, volcanic activity and seismic activity are increasing.

Actually, the same thing happened about 1000 years ago. Two years after the 869 Johgan Earthquake in Tohoku Region, Nigata's Mt. Choukai erupted, and nine years after that a huge earthquake occurred in Kanto region. A further nine years later, the Nankai Trough Mega earthquake occurred. Again, Mt. Fuji erupted five years before the Johgan Earthquake. In other words, the current Japan is considered to be in the same seismic activity period like it was about 1000 years ago.

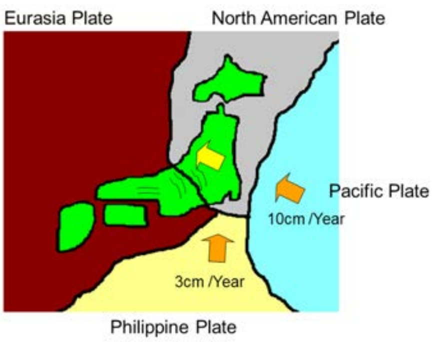


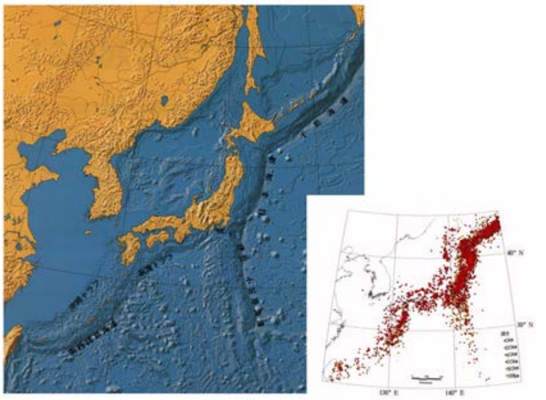


The figure above shows the positions of plates & the figure below is the distribution chart of earthquake occurrence. You can see many earthquake occurs at the boundary of plates. Also, there are more earthquakes in the trench where the plate submerges under another plate than the ridge where the plate generates.

There are many earthquakes in Japan because the Japanese archipelago is situated in a very unique place in the world where four plates collide one another.

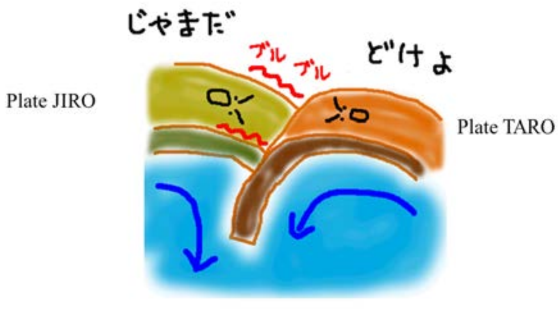
To the east of the Japanese archipelago is the Japan trench and to the south is the Nankai trough. On the trenches where the oceanic plate sinks, those with a depth of less than 6000 m are called troughs. It is understood that earthquake mainly occurs along the trench and trough.

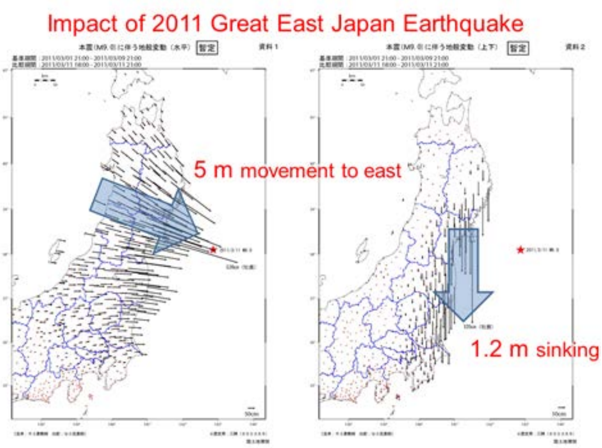




When a plate slips into another one, the opposite plate resists and strains accumulate. When the limit is reached, the boundary (fault) of the plate is destroyed and a backward push occurs. The shock waves that originates at that time is called Earthquake.

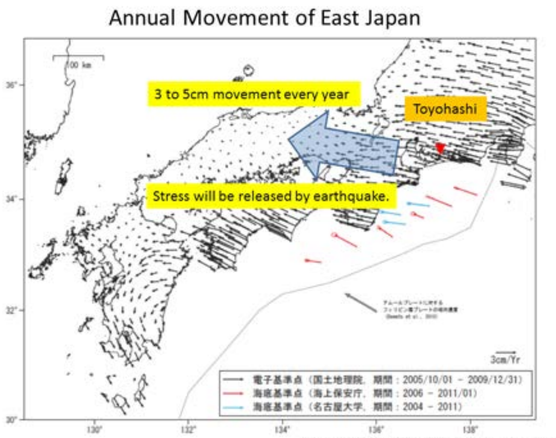
Collision of Plates produces Earthquakes





In the Great East Japan Earthquake, the distortion constituted by strain was released at once and the Japanese archipelago moved up to the east by about 5m. Again, there are even places where the ground sank more than 1m. Such ground motion can be accurately obtained from the GPS observation by the electronic reference point stretched all over the country.

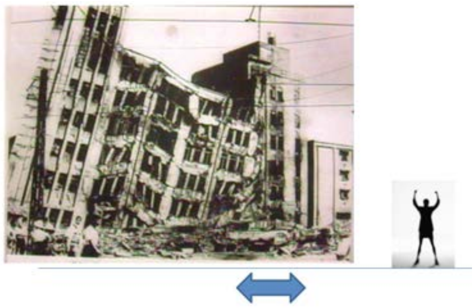
On the other hand, there is the Nankai Trough in the south of West Japan. The Philippine Sea plate is subducting with a speed of about several centimeters per year into Japanese archipelago and pushing it northwest. As no big earthquake has occurred in the past 70 years, it has pushed more than 2m by a simple calculation. The distortion has not been released yet. It’s a matter of time that distortion accumulated by strains will release all at once by means of Earthquakes.

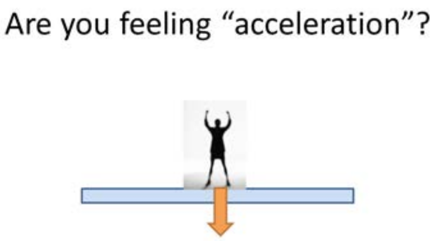


（出典：地震調査研究推進本部ホームページ）

Why building is weaker than human?

If the earth shakes violently due to Earthquake, it’s difficult to stand, also may lose balance and fall down. But it’s rare to occur serious injury. On the other hand, buildings that are supposed to be stronger than humans may collapse due to earthquake. Why is human Ok but not the building? For this, let’s think about the forces acting on the building in case of earthquake.

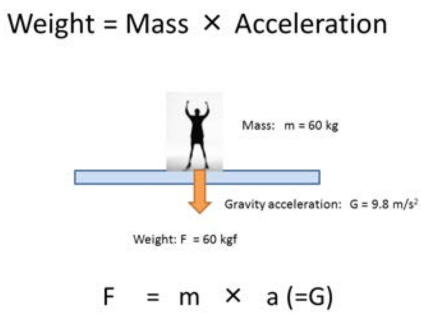


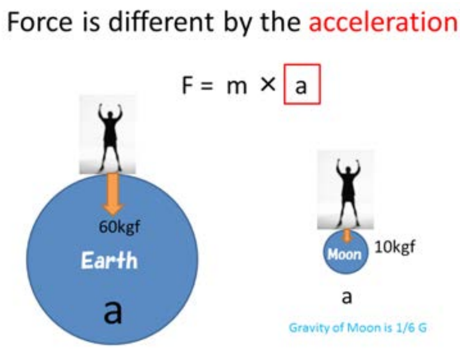


If there is no floor, this human body will fall down. This is because of the attraction of earth. The falling speed will gradually increase. The acceleration behind it, is the gravitational acceleration due to earth’s gravity.

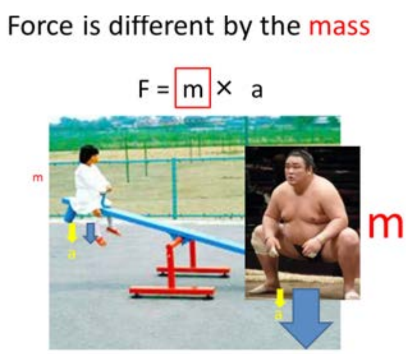
Your weight represents the scale of attraction force of the earth working on your body. The value is expressed as the product of mass and gravitational acceleration.

Mass is unique to things and the value of gravitational acceleration is different between the earth and the moon. If your weigh your weight on moon which got less gravity, the value will be much smaller. Since the gravitational acceleration of the moon is one sixth of the earth, the weight will be also one sixth of earth’s.



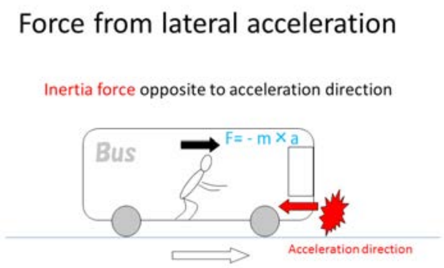


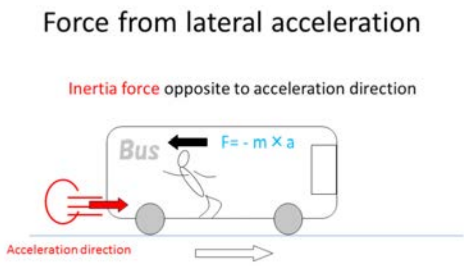
Since it is on the same planet, the downward gravitational acceleration is the same but the mass is different. Therefore, the downward force is larger for Sumo wrestler than of a child.



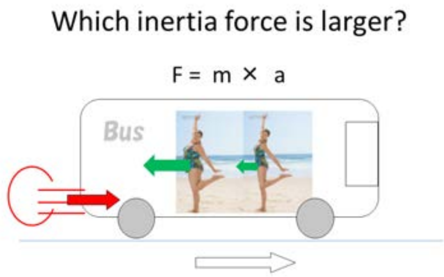
Acceleration is not always downward. When bus stops suddenly, the body is likely to fall forward. At this time, the force product of mass and acceleration works on the body. This force is called inertia force. Acceleration of the inertia force is opposite to the acceleration trying to stop the bus.

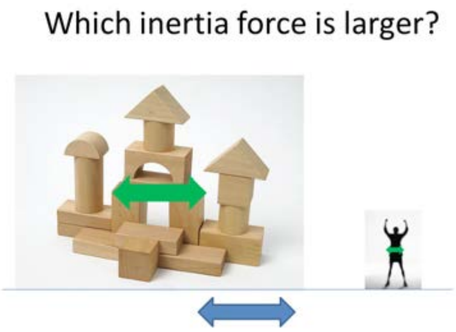
When the bus starts suddenly, the body will fall backward. Also this time, inertia force which is a product of mass and acceleration works on the body.





When a fat and a thin persons are on the same bus, at that time if the bus suddenly starts from stoppage, which person will have larger inertia force? Since the acceleration is same, the inertia force will be larger for fat person as the mass is larger.

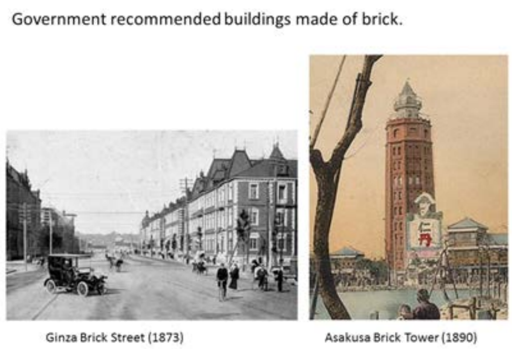




Well, let's go back to the first question. When the earth shakes due to an earthquake, as the building got much larger mass than the person standing on the ground, there will be larger inertia force working on the building accordingly. In other words, the fact that the building collapses due to earthquake even though it doesn't affect person is because the building can't support the inertia force. Generally buildings are built strong enough top to bottom so that they can support against gravitational forces but weak against inertia force due to earthquake which works left to right and vise versa.

As a result, structures built with stones and bricks (commonly known as masonry) is likely to collapse due to earthquake which is not suitable for earthquake prone countries like Japan. But there are lots of masonry building overseas, and as a result, there are lots of fatalities due to building collapse during earthquake.

After the Meiji restoration, a number of western style brick buildings were built. After the incident in which a building in Ginza street in Tokyo was destroyed by fire, it was rebuilt by brick construction. Also in Asakusa of Tokyo, there was the tallest brick tower in Asia of that time.

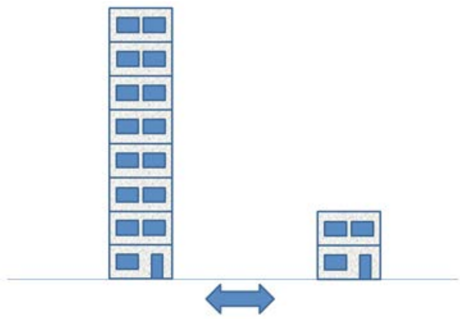


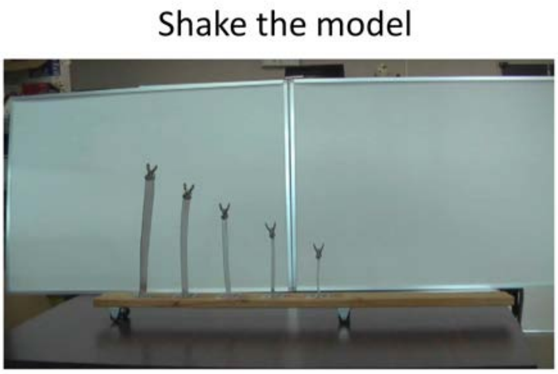
1891 Nobi Earthquake (M8.0)/ 1923 Great Kanto Earthquake(M7.9)

However, brick buildings suffered great damage in the Nobi earthquake of 1891 and the Great Kanto earthquake of 1913. Therefore, after that, masonry buildings were strictly regulated by law and disappeared from Japan.

Which building is safer?

Which building is safer in earthquake, the high rise one or the low rise one? Considering the inertial force which works due to the shake of earth, larger mass of high rise building seems to be a disadvantage for it. However, since the inertial force is the product of mass and acceleration, you must also consider the magnitude of the acceleration caused by the shaking of the building.

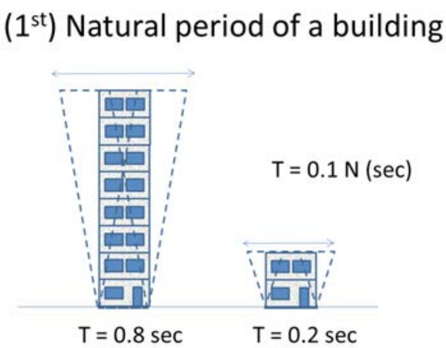


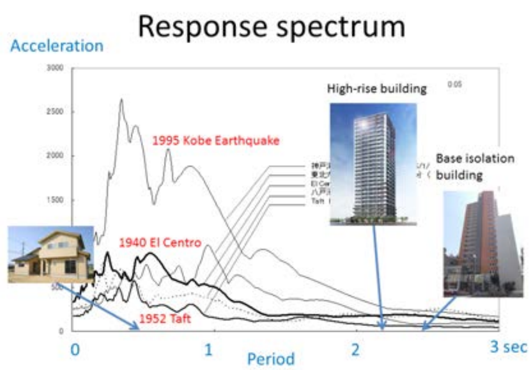


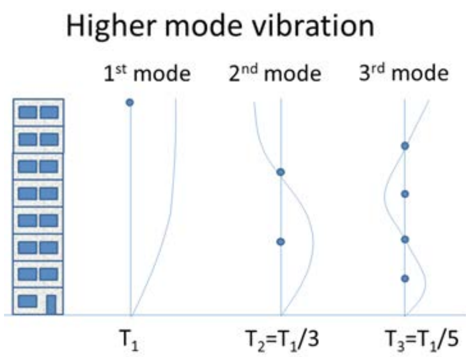
Let's shake these models in real. If you shake swiftly, the low rise building will vibrate but if you shake slowly, the high rise one will vibrate. Why does this phenomenon occur?
Actually, the building has it's own vibration speed and the time taken to complete one vibration is called natural period. When the period of the vibration of earth coincides with the natural period of the building, the inertia force works with good timing and the shaking of the building of that natural period gets amplified. This is called resonance.

The rough value of natural period of a building is found by multiplying 0.1 to the number of stories. It is 0.8 second for 8 stories and 0.2 second for 2 stories approximately.

A graph plotted with the maximum acceleration of building's shaking at each natural period is called the 'acceleration response spectrum'. Let's calculate the acceleration response spectrum for various earthquake motions.
From the graph, we get that the mountain of the spectrum covers roughly 1 second or less of the natural period and the middle and low rise buildings with shorter natural period shakes heavily, on the other hand, if the natural period goes beyond 1 second like that of high rise and base isolated buildings, the shaking gets gentle.





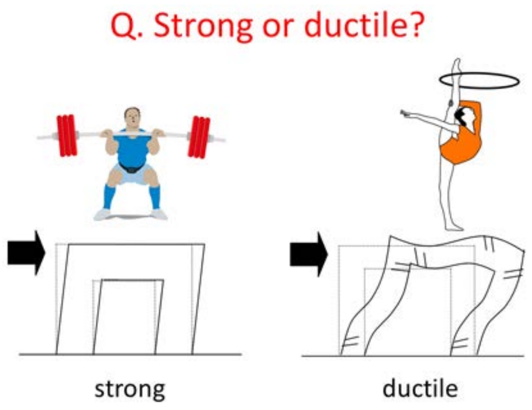


With the increase of number of floors, the buildings may shake like wriggle in the middle. Since the shape of the shaking is unique to the building, it is called natural vibration mode. From the order of long oscillation period, we have first mode, second mode, third mode to till equal to the number of stories, that amount of mode.

In a skyscraper, roughly the shape of the natural vibration mode is a sine function. The ratio of the next natural period to the first natural period is the ratio of the wavelengths (1, 1/3, 1/5, ... in order). Namely, in a skyscraper with a natural period of 2 second of 1st mode, the natural period of 2nd mode will be approximately 0.7 second (1/3 of 2 seconds), the natural period of the 3rd mode will be around 0.4 second (1/5 of 2 seconds). In a rattling like oscillation, the higher modes of the shorter natural period are excited and the building shakes. On the other hand, in a gentle oscillation, first mode of long natural period gets active and the higher floors shake greatly.

How to make the building strong against

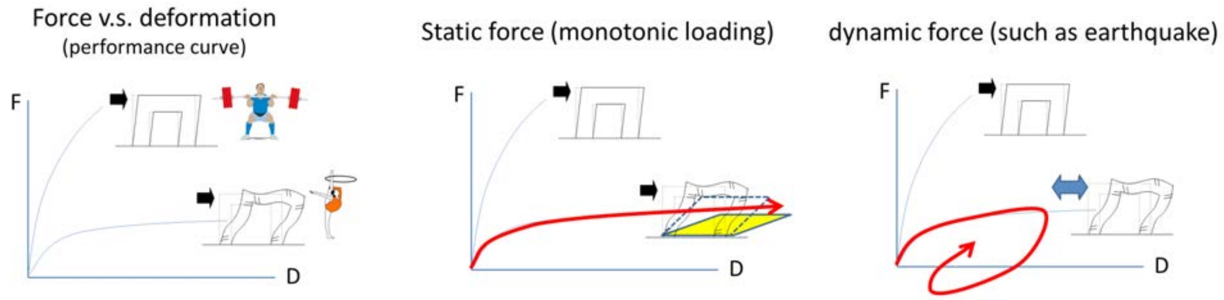
What kind of construction is suitable to prevent buildings from collapsing due to earthquake? One way is to make the columns and the beams stronger so that even if an earthquake comes, it stays well composed. But it is uneconomical to make it too strong only for the earthquake that rarely comes. So at the time of an earthquake, considering the building to be broken somewhat, but not enough to fall over , the columns and the beams are made ductile. Specifically, we use metal fittings at wooden joints or densely put reinforcing bars in the reinforced concrete members. In this way, the basic of earthquake resistant structure is a mechanism to withstand earthquakes by combining strength and ductility.

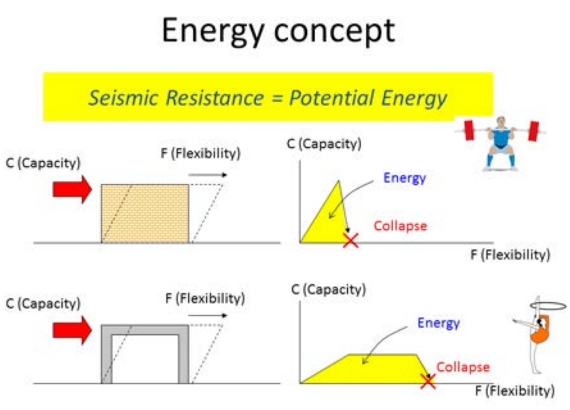


Strong types will be able to withstand large horizontal force, but not too much deformation. On the other hand, the soft type can only withstand a little force, but it will deform considerably

To tell you the truth, soft type is not good against wind and snow which put force for a long time. Since the deformation progresses gradually with time, after some time it will collapse. So it’s not good enough.

During earthquake, shakes will change to the opposite direction before getting too large deformation, therefore, it’s fine to accept ductile behavior. This is the reason behind soft type building being good against Earthquake.

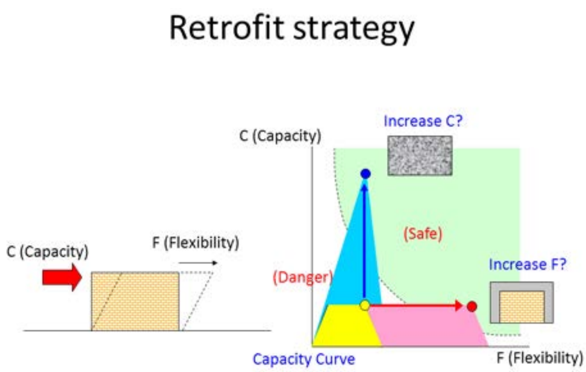




To construct earthquake resisting building, we have learned that there are two types. Strength type (Solid type) that makes the building sturdy and ductile type (soft type) that deforms without collapsing even if it breaks somewhat. At this time, if the area (which is called potential energy) of the force vs deformation graph is same for two buildings, the seismic performance can be considered to be equivalent.

For example, how can we retrofit when the seismic performance of the original building is small, that is, when the potential energy that can be absorbed by the building is small?

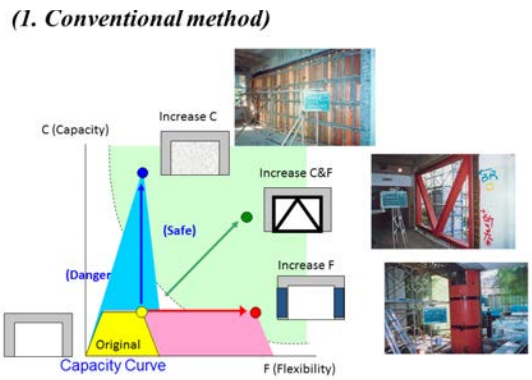
One way is to increase the walls and strengthen them. Another way is to roll carbon fiber around the column so that it doesn’t collapse but can deform. Both of these process can increase potential energy.



Now let me explain the traditional method of seismic retrofitting technology of the buildings.

As a way to increase the strength, openings are closed completely with reinforced concrete wall. This is very common. As a method to increase the deformability (ductility) , there is a method of covering the columns with iron plate or carbon fiber. In addition, there is a method of putting steel brace (called brace) which is an intermediate method of the former two. In particular, this method is often used when you want to let in external light in a south facing window like a classroom of a school.

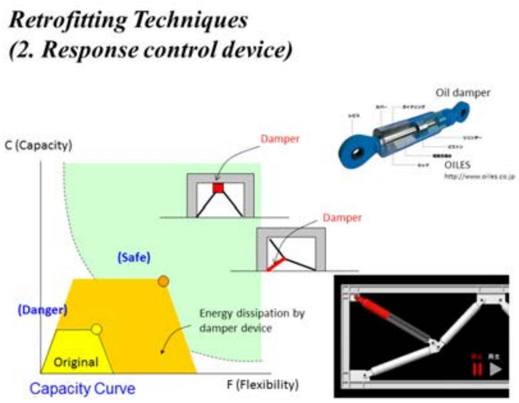
This building of Toyohashi University of Technology is reinforced by using brace on the outside.

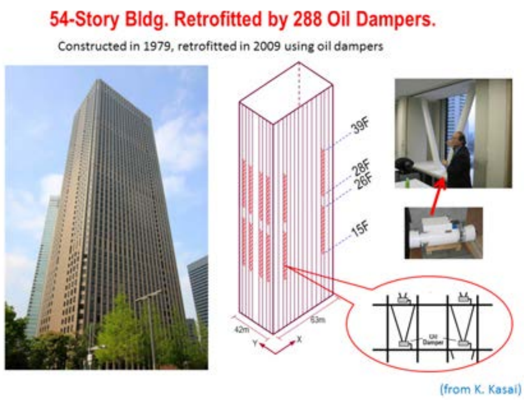


There is also method to absorb energy by putting special equipment inside the building. This device is called response control damper. The seismic performance of a building retrofitted with damper improves as the absorbed energy by the damper adds up to the potential energy of the building.

Oil damper is widely used as viscous damper. When the piston moves inside a cylinder filled with oil at a velocity, it generates a resistance force proportional to the velocity. It's mechanism is almost same as the shock absorber that suppresses vibration in a car.

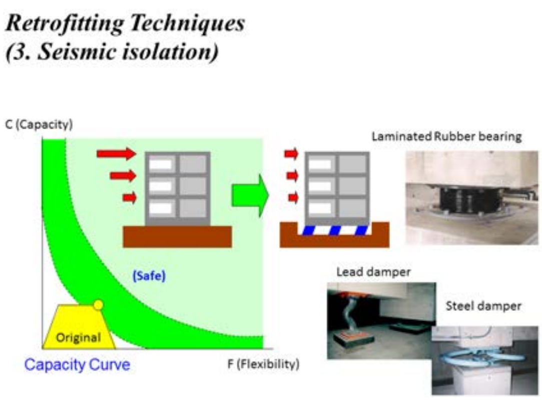
For example, oil dampers are often used to reinforce high rise buildings. In this example, 288 oil dampers were installed in the middle floors of a high rise building after construction was finished.

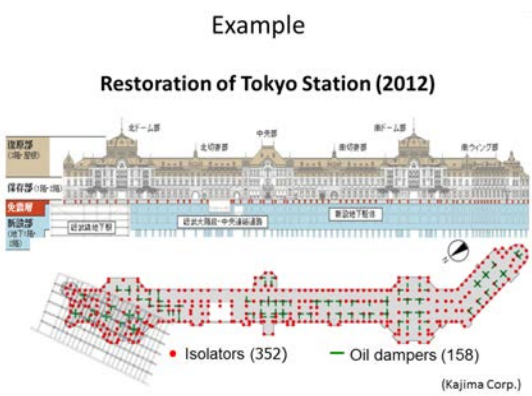




For example, if you don't want braces or dampers to be attached on buildings for retrofitting such as of historical preserved buildings, you can put rubber foundation under the building and reduce the inertial force caused by the earthquake to make it same. This structure is called seismic isolated structure.

Tokyo station is restored to the appearance about 100 years ago. Supported by 352 seismic isolation rubbers, it was possible to make it safe, even the structure at that time.

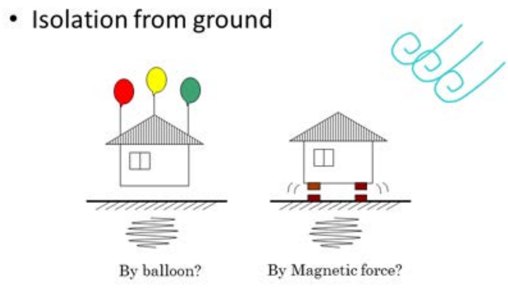




What is base-isolation?

Let’s try to understand the mechanism of seismic isolation while conducting a simple hypothesis. First of all, let us consider various ways in which the building won’t shake during an earthquake.

Perhaps the ultimate way would be floating the building in the air. With current technology, like a linear motor car, you can even float a train with the power of magnetism. So it’s not a dreamlike tale. But if a building floats in the air, it should be hard to get in or out. Besides, if the wind blows, it may be blown far away.

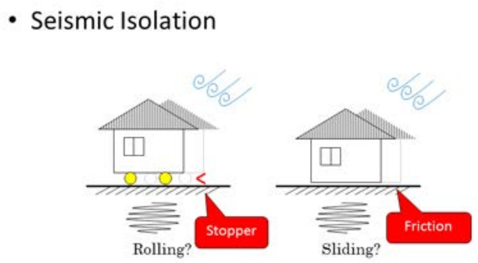


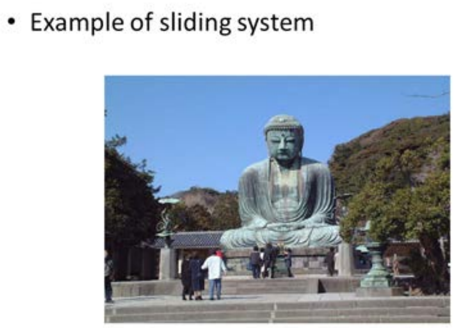
For now, let’s just give up on floating buildings and think about another way.

For example, how about laying rollers under the building? Or how about putting the building on a sliding table and slide it in case of an earthquake? In either case, when the earthquake occurs, the building rolls and slides. So the lateral force transmitted to the building can be reduced.

Weather forecast informs you in advance if typhoon comes. So when a typhoon comes in, you should fix the building with a stopper and then remove it after typhoon leaves. While sliding a building, there may be a method of adjusting the friction coefficient so that the building doesn’t move with the force of the typhoon and moves only in the case of slightly big earthquake.

The Great Buddha of Kamakura has a stainless steel plate laid between the Buddha statue and the pedestal so that the Buddha statue slides at the time of an earthquake.

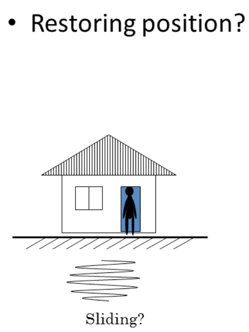


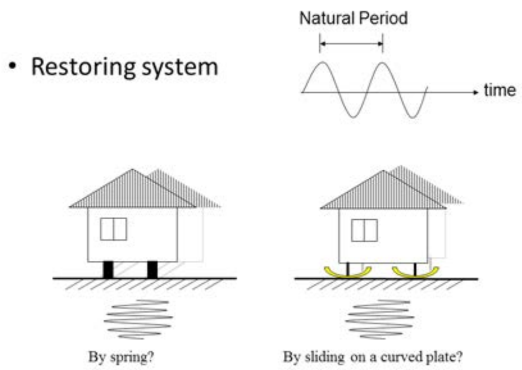


Kamakura statue was rehabilitated in 1960 adopting sliding foundation.

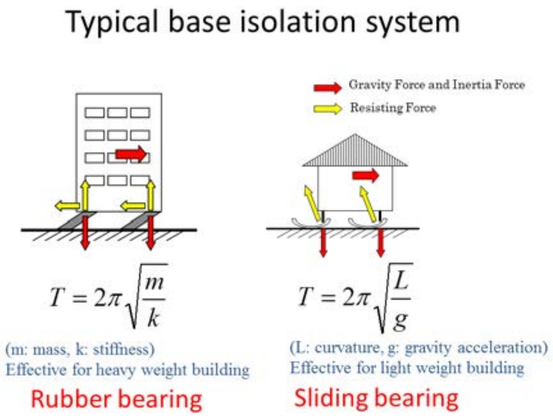
In the method of rolling or sliding a building, the building may deviate greatly from its original position after the earthquake. So, what kind of device can you make the building remain in its original position, even after the earthquake?

For example, how about connecting the building and the foundation with a spring and returning it to its original position by the force of the spring when the building moves? A soft rubber base looks good as it supports the weight of the building and deforms in the horizontal direction. Alternatively, there is a method of placing the building on a concave surface and slide it over it. Even if the building slides, it returns to its original position with the force of its own weight.

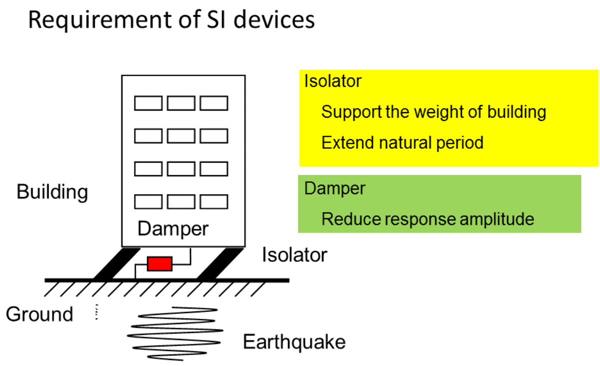




To bring it back by using spring method, the natural period will be proportional to the square root of the weight. In other words, the heavier the building gets, the longer will be its natural period. It is also inversely proportional to the square root of the spring stiffness. In other words, you can prolong the natural period, by supporting the building with (soft) spring of less stiffness.



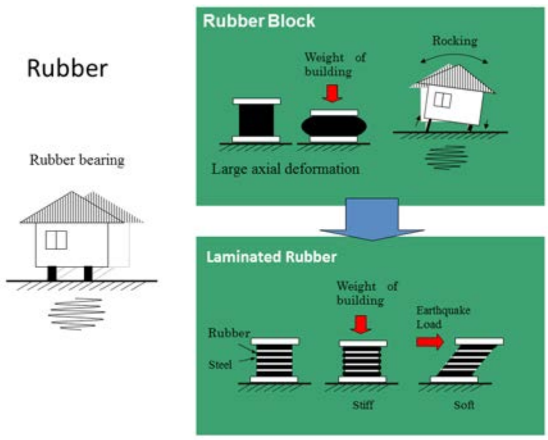
On the other hand, in the method of sliding on a concave surface, the natural period is proportional to the square root of the concave curvature radius. In other words, the more concave the surface is, the longer will be natural period of the building. Since it doesn't relate to weight, it is suitable for base isolation of light houses. It is also common to use both methods at the same time.

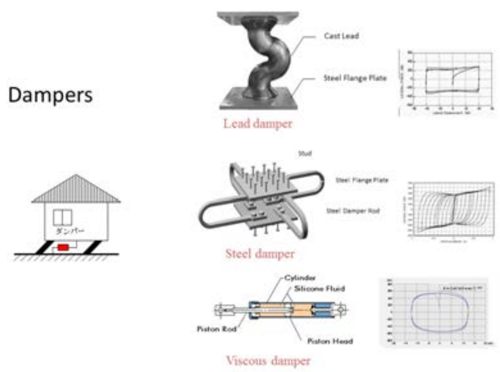


In addition, let's add a damper that will attenuate the sway of building quickly. As already explained, the damper is a device that absorbs energy of vibration depending on the amplitude of the vibration. By using a damper, you can gradually reduce the sway of the building.

As described above, with the base isolation structure, by using the isolator that supports the weight of the building and prolongs the natural period of the building and the damper that damps the shaking effectively, the sway of the building at the time of the earthquake can be effectively reduced.

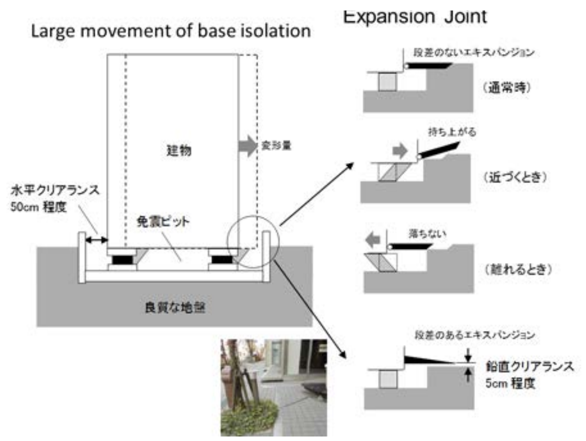
In 1969, the first base-isolated building in the world using rubber foundation was built in Skopje, the capital of Macedonia. Since the mass of soft rubber deforms not only in the horizontal direction but also in the vertical direction, when the earthquake occurred, there was a problem that the building was tilted due to the combination of the horizontal swing and the vertical swing. That is why laminated rubber bearings were invented as rubber bearing, which is hard on the vertical direction but soft in the horizontal direction. The laminated rubber has a structure in which thin rubber layers of several millimeters and thick steel plates are laminated alternately and bonded. By doing this, the steel plate constrains the lateral bulging of rubber along with the vertical deformation, and the vertical deformation due to the weight of the building can be kept small. On the other hand, it does not restrain the shear deformation of the rubber against the horizontal force, so it deforms smoothly in horizontal direction. By the invention of this laminated rubber, a seismic isolation structure that can be used practically, is made possible.





Damper used in the seismic isolation system has various shapes which makes it possible to cover relatively large deformation and to deform in any direction.

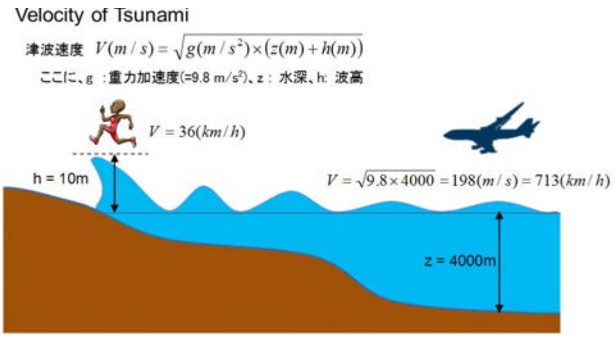
In the seismic isolation structure, it is necessary to provide an obstacle-free space (horizontal clearance) around the building so that the base isolation layer can deform. Because there are seismic isolation pits in the basement of a base isolation building, usually by setting railings and plantation around the building, prevents people from falling into the pits. Also, at the entrance and the exit, we set up a cover (expansion) to move with the building.



Let's look at the base isolation buildings in foreign countries.
In the northern part of Iran, an earthquake prone country, there is a elevated-floor building with a foundation that combines logs side by side vertically and horizontally. It is said that this construction dates back a few hundred years ago. So in the event of an earthquake the log will roll and reduce the shaking of the building. Therefore, it is a splendid seismic isolation structure. Similar devices are also found in Algeria, another earthquake prone country. Wooden logs are inserted between brick arch and pillars in the 18th century temple in Kasbah, in the capital city of Algiers, to reduce the seismic force.

Even base isolation is a splendid system, there are some concerning points.
Since the isolation device is underneath the building, after the earthquake the device may be broken. If left untouched, the seismic isolation device will not work at the event of next earthquake and it is dangerous. After a earthquake of mid or large scale, let the manufacturer check the state of the equipment.

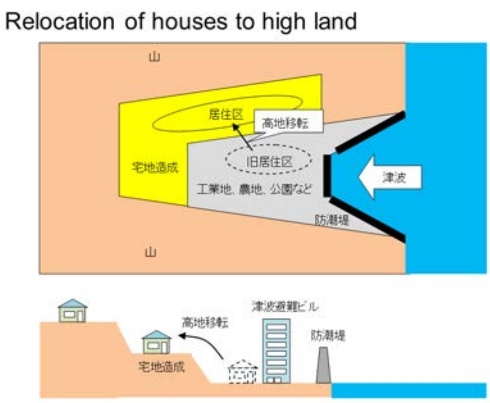
How to prepare against Tsunami

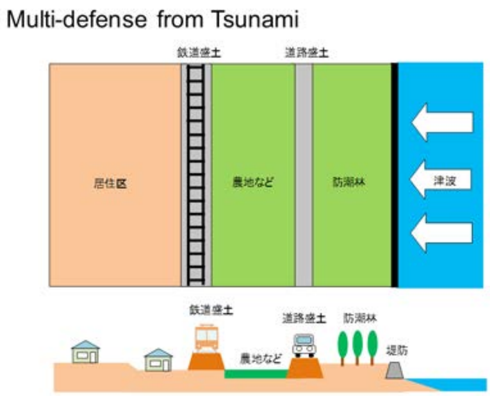


Let's change the subject about tsunami after an earthquake.
In the Great East Japan Earthquake, about 90% of nearly 20,000 victims died because of the tsunami. The speed of the tsunami is determined by the water depth and wave height. The average depth of the Pacific Ocean is about 4000 meters, and the speed of the tsunami traveling through this depth is about the same as the jet plane speed of about 713km/h. While approaching land, the depth of the tsunami becomes shallow and the speed slows down. But as the back tsunamis catch up, as a whole it gets swelled. In addition, waves are overlapped from left and right in the infiltrated bay and the wave height increases.
If the height of the tsunami on the land is assumed to be 10m, the speed will be 36km/h, and the tsunami will approach at a speed comparable to that of the athletes of 100m Olympic race.
How should we prepare for the tsunami?

An effective way to eliminate the damage caused by the tsunami is to relocate the residence to a higher ground where the tsunami does not reach. However, for those who are engaged in the fishing industry, it is necessary to develop transportation routes to the seaside, embankments and tall tsunami evacuation building.

In plain areas without high ground, multiple defensive steps that attenuates the tsunami force are necessary such as coastal embankments, sand dune, tidal forest, road embankments, etc. along with limited land use.





Japan obliges municipalities to announce the flood area and depth of water for the largest class tsunami. The tsunami hazard map created there, is the basis for maintenance of evacuation places, evacuation routes etc. Do you know whether the area where you live could be flooded by the tsunami or not?

When a major earthquake occurs, a wide range of area suffers at one time. If you can not use the lifeline such as water, electricity and gas, it will hinder living. With the stoppage of public transportation, people won't be able to go back to their home and if the roads get congested, there will be times when fire fighters and ambulance won't be able to reach to the spot in time. To prepare for earthquake disasters, it is important to take three actions. [Self help] to protect yourself and your family, [Co-aid] to help each other in the region and [Public assistance] to receive rescue and support from the country and local governments.

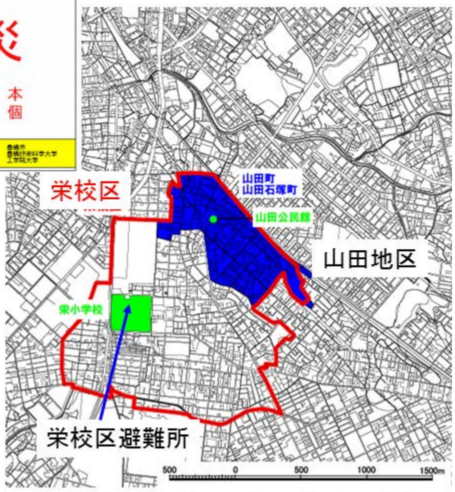
Toyohashi city is at the risk of Tokai and Tonankai earthquake for a long time and disaster prevention activities have been carried out enthusiastically. Let's introduce the activity with the slide borrowed from Prof. Hisada of Kogakuin University. Toyohashi University of Technology also participates in this activity.

In ordinary disaster prevention drills, it is required to act in an orderly manner as an organization in accordance with preset scenarios. However, with the implementation of earthquake, it is rare to go according to the scenario. Everyone needs to respond flexibly according to situations that change from moment to moment.

Therefore, in disaster drills conducted in Yamada Town in Toyohashi City in 2006, a method was adopted in which damage signs were installed randomly in the city without notifying the residents and they made response according to the damage sign. This method is called Emergency response training.

Realistic Disaster Mitigation Drill
Toyohashi city in 2006

Placards of various disaster



（Slide from Prof. Hisada, Kougakuin University）

For example, participants in disaster prevention drills will immediately execute initial fire fighting actions when they find a fire sign in the city. At the same time, the situation of the damage is reported to the residence association and the residence association creates a disaster map by summarizing the report. The summary includes the spot of fire occurrence, which buildings has collapsed. In the end, this information is kept preserved at the disaster prevention center in Toyohashi city.

This kind of fabulous training has been done in the past but unfortunately it is not continued since then. I would like to discuss with everyone about how these activities can be continued in near future.

Immediate action and information shearing

Fire extinction

Map of damage

Evacuation

Support of elder person

Check name list

Headquarter

（Slide from Prof. Hisada, Kougakuin University）

English

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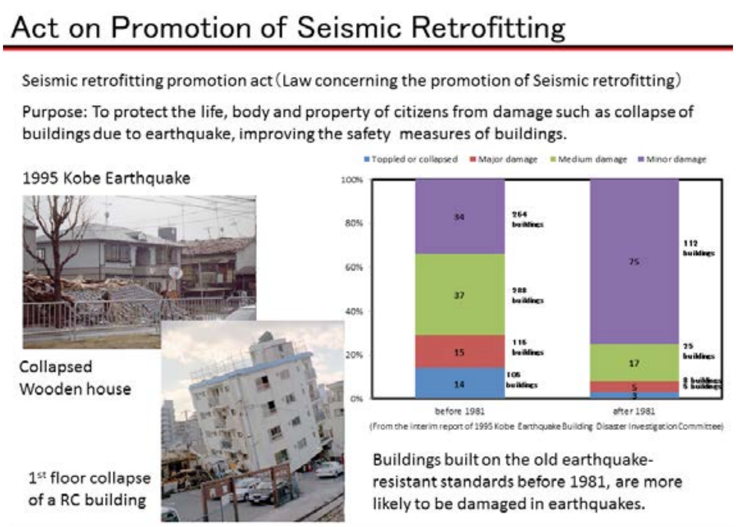
建築・都市システム学系准教授

Diagnosis and Reinforcement of buildings

Civil & Architecture Department

Tomoya Matsui

Contents

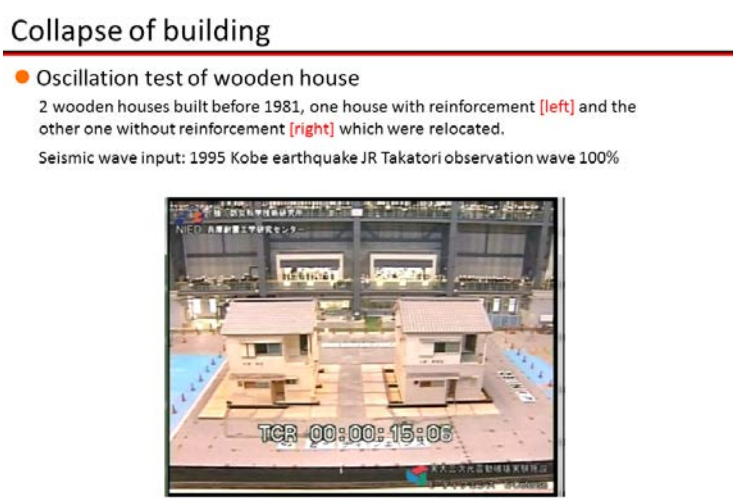


The law concerning the promotion of seismic retrofitting of buildings which is called earthquake-proof repair promotion law, was established and enforced on the occasion of the Kobe Earthquake of 1995, when structures including buildings suffered severe damage. The purpose of this law is to improve the safety of buildings against earthquakes by taking measures to promote seismic retrofitting of buildings in order to protect the life, body and property of citizens from damage such as therefore, assisting in securing public welfare.

The seismic safety standard was revised in 1981. From the result of damage investigation, it was revealed that the buildings built before 1981 were more damaged than the buildings built after 1981. As a result, the necessity for seismic diagnosis and retrofitting of existing buildings, especially buildings built with old earthquake resistance standards before 1981, has increased.

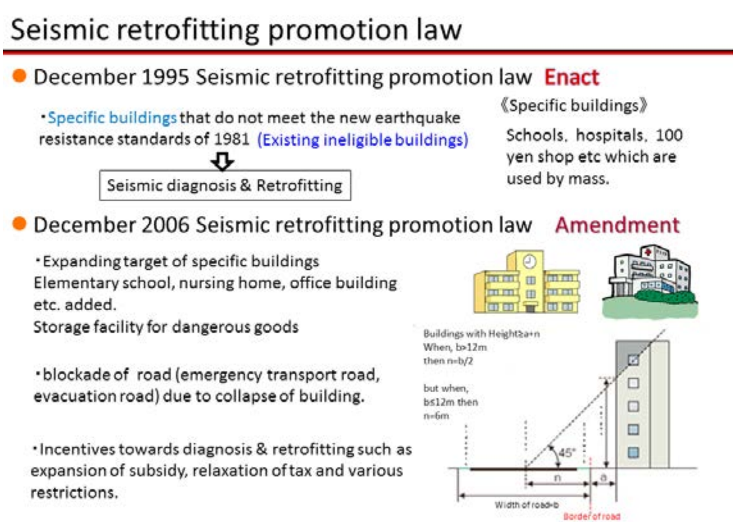
This video is about how building collapses on occasion of an earthquake.
It is a seismic experiment of a 6-story reinforced concrete building.

Video：
National Research Institute for Earth Science and Disaster resilience
http://www.bosai.go.jp/hyogo/index.html (2014.10)



Let's see this video.
2 wooden houses built before 1981, one house with reinforcement [left] and the other one without reinforcement [right] which were relocated.
Building without reinforcement collapse, housing with reinforcement does not collapse.

Video：
National Research Institute for Earth Science and Disaster Resilience
http://www.bosai.go.jp/hyogo/index.html (2014.10)



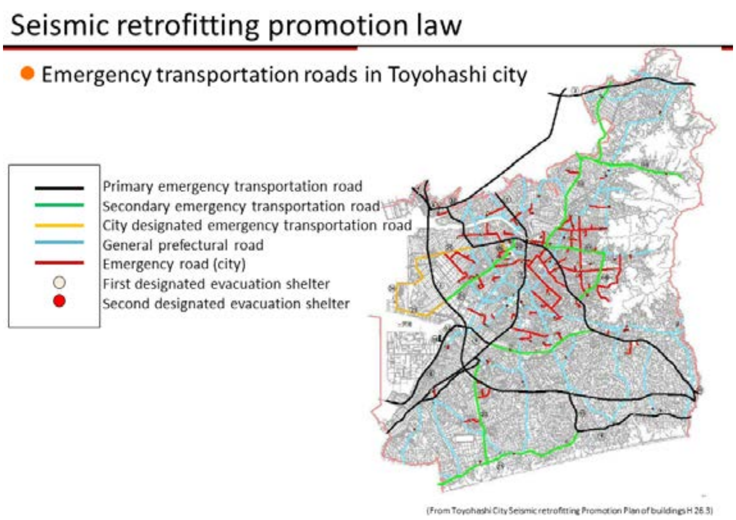
In the Seismic Retrofitting Promotion Act of December 1995, buildings built with old earthquake resistance standards used by a large number of people are designated as "specific buildings". The owners of such buildings must take all reasonable endeavors to perform seismic diagnosis (checking earthquake resistance), and if necessary, in case the earthquake resistance performance does not satisfy the new earthquake resistance criteria, must implement seismic retrofitting; as an obligation.

Subsequently, the Seismic Retrofitting Promotion Act was revised in December 2006.

In addition to the expansion of the range of specific buildings, incentives related to seismic diagnosis and retrofitting were added.

In the expansion of the range of specific buildings, elementary school, nursing home, office building, storage facilities for dangerous goods were added. In addition, buildings that might collapse and block the emergency transportation and evacuation roads due to earthquake were added. As shown in the figure, when the width of the road exceeds 12 m, then buildings with height equal to or greater than the distance from the center of the road to the building, and when the width of the road is 12 m or less, buildings with height greater than or equal to 6 m will be subject to specific buildings.

This figure shows Emergency Transportation Road in Toyohashi City.



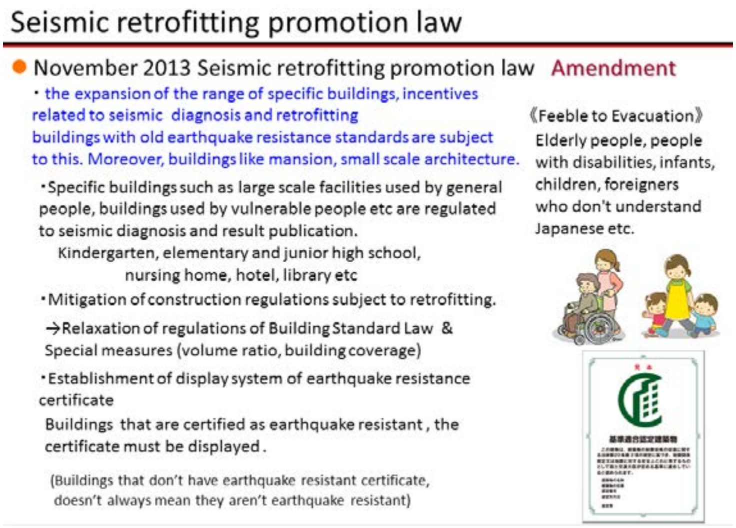
An emergency transportation road is a road on which emergency vehicles such as rescue, emergency, medical treatment, fire fighting activity and goods transport preferentially pass when the declaration of warning of the earthquake or any disaster occur, and it is based on uniform selection criteria for country, prefectures and cities.

There are four kinds of emergency transportation roads, for example, the primary emergency transportation road is a road that communicates important ports, airports, wide-area logistics bases, etc. and carries out wide-area emergency transportation.

The second emergency transportation road is a road that links the primary emergency transportation road, municipal government office, major disaster prevention base (government agency, public agency, police station, fire department etc).

The evacuation centers are also shown in the figure. In Toyohashi City, there are primary designated evacuation shelter and secondary designated evacuation shelter. The primary designated evacuation shelter is set as a place to evacuate in the event of loss of one's own home, like when it is damaged so badly that unsuitable for living in the event of a disaster or in case when there is a risk of being damaged. 70 school district city halls are specified as primary designated evacuation shelter.

The secondary designated evacuation site is set as a shelter to be opened when the first designated evacuation shelter exceeds the capacity, and 90 facilities such as elementary and junior high schools are designated in Toyohashi city.



Due to the occurrence of a huge earthquake such as the Great East Japan Earthquake, the imminence of the Nankai Trough's massive earthquake and the Epicentric earthquake of Tokyo is obvious. Steady proceeding with earthquake resistance of buildings, and reducing human and economic damage as much as possible is now an urgent necessity.

Therefore, the Seismic Retrofitting Promotion Act was further revised in November 2013.

Here, we expanded the range of the specific building. Buildings that were built according to the old earthquake resistance standard & do not meet the current earthquake resistance standards, are subject to the seismic diagnosis & retrofitting obligation. In addition, it is mandatory to do seismic diagnosis of the specific buildings such as large-scale facilities used by general people and specific buildings used by vulnerable people. It's an regulation to publish that result.

Meanwhile, as measure for smooth promotion of earthquake resistance, restrictions can be relaxed on constructions subject to the approval of the retrofitting such as the regulation on the volume ratio and building coverage can be eased for the qualified buildings.

In addition, the subsidy is introduced for seismic diagnosis & retrofitting, and income tax deduction for retrofitted buildings are being expanded.

It has been 20 years since the establishment of the renovation promotion law, and conversion of buildings to earthquake resistance has made good progress.

The table shows the ratio of earthquake resistant buildings in Toyohashi City. The number of buildings which are seismically diagnosed or statistically estimated that they have earthquake resistance (meets earthquake resistance criteria)is divided by the total number of buildings, is building conversion rate to earthquake resistant. As of 2003, the building conversion rate to earthquake resistant was 78.8%, but rate has improved to 88.8% as of April, 2013. So it can be said that conversion of buildings to earthquake resistant has made good progress. Moreover, the target until the fiscal year 2025 is assumed to be 90%, and the figure is almost likely to be achieved. Incidentally, in fiscal year 2020, the goal is to reach the rate of 95%.

The earthquake resistant building rate of Toyohashi

- Percentage of earthquake-resistant buildings in Toyohashi City

data: April, 2013

Classification	Number of buildings	Buildings built after New earthquake resistance law (earthquake resistant)①	Buildings built before New earthquake resistant law		Earthquake resistant buildings ①+②	Percentage
			Earthquake resistant②	Not earthquake resistant		
Wooden house	82,100	54,600	13,630	13,870	68,230	83.1%
Excluding wooden house	59,300	48,000	9,310	1,990	57,310	96.6%
Sum	141,400	102,600	22,940	15,860	125,540	88.8%

(From Toyohashi City Seismic retrofitting Promotion Plan of buildings H 26.3)

Building conversion Rate to Earthquake resistance: The number of buildings which are seismically diagnosed or statistically estimated that they have earthquake resistance (meets earthquake resistance criteria)is divided by the total number of buildings.

- Current condition:

Buildings: 78.8% (2003) → 88.8% (2013)
Specific existing incompetent buildings (public): 50 buildings (2007) → 8 buildings
Specific existing incompetent buildings (private): 488 buildings (2007) → 330 buildings

- Target:

Fiscal year 2015 90% (Cabinet decision in Fiscal year 2006)
Fiscal year 2020 95% (Cabinet decision in Fiscal year 2010)

If we breakdown the conversion rate to earthquake resistance, then we get about 14,500 new buildings, about 9,900 renovated buildings, about 1000 buildings with earthquake resistance facilities.10% of these buildings had government subsidies.

Existing ineligible specific buildings are decreasing as well, so far there are only 8 public buildings and 330 private buildings left.

Subsidy for Seismic diagnosis & Retrofitting in Toyohashi

(Partially extracted)

- Subsidy and assistance to Seismic diagnosis & Retrofitting

・Implementation of free seismic diagnosis for wooden houses which were built before the new earthquake resistance law.

・Assistance for seismic diagnosis cost of non-wooden houses before new earthquake resistance law
2/3 of the cost, the maximum limit is 86 thousand yen

- Subsidy for Seismic Retrofitting

・If the value of free diagnosis of wooden house is less than 1, then the value is increased to 0.3 or more that; and if the value is 1 or more, then the 23% subsidy of Seismic retrofitting cost, 2/3 of the design cost, maximum 1.2 million yen will be provided by Government.

- Subsidy for dismantling work (Rebuild)

・If the value of free diagnosis of wooden house is 0.7 or less, then 2/3 of dismantling construction cost will be covered by subsidy; maximum 200 thousand yen.

《Seismic diagnosis cost》
Depending on the scale, Seismic diagnosis cost of general wooden houses is about 15 to 25 thousand yen

《Seismic retrofitting cost》
Seismic retrofitting cost of most of the wooden houses is about 1.5 to 2 million

(From Toyohashi City Seismic retrofitting Promotion Plan of buildings H 26.3)

It is very important to ensure earthquake resistance of people's residence in order to preserve human lives at the time of earthquake and secure residents after the earthquake. For that purpose, each municipality is preparing a subsidy system in order to conduct seismic diagnosis, confirm safety, and promote seismic retrofitting.

As an example of the subsidy system related to seismic diagnosis & retrofitting, partly excerpted subsidy system in Toyohashi city is shown.

There are subsidy for seismic diagnosis, retrofitting & disassemble work etc. As for seismic diagnosis assistance, seismic diagnosis of wooden houses built before new earthquake resistance law can be implemented free of charge, which is considered to lead to promotion of seismic retrofitting towards the target value of earthquake resistance rate.

Depends on the scale of construction but anyway Seismic diagnosis cost of general wooden houses is about 15 to 25 thousand yen.

Towards promotion of Seismic retrofitting

Buildings constructed complying with the old earthquake resistance law have incentives for Seismic diagnosis and retrofitting.

First, Need to confirm whether the building was built before 1981 or not.
For buildings built before 1981
→Seismic diagnosis and retrofitting investigation
→Assistance and subsidy

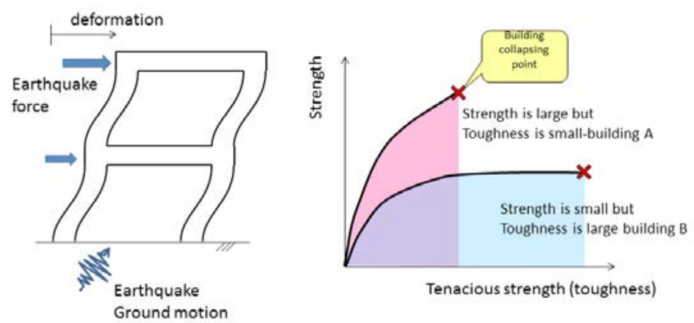
While seismic diagnosis, seismic performance of buildings depends on four factors: strength of building, tenacity, shape, and degree of deterioration age.

Here, important part is “strength” which is the strength of the building and “toughness” which is tenacious strength against deformation.

When earthquake occurs, the inertial force due to the earthquake motion acts as a horizontal seismic force to buildings causing deformation.

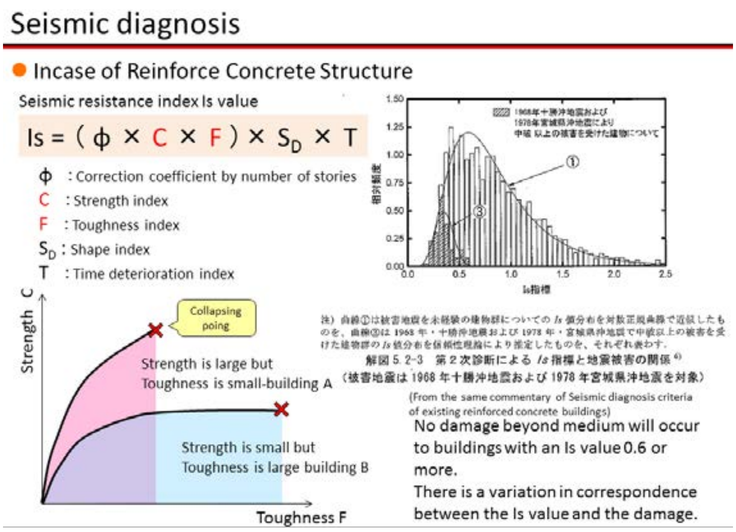
Approach to Seismic Diagnosis (review)

Seismic performance by seismic diagnosis
=(strength × toughness) × shape × degree of deterioration



In the figure on right, it’s assumed that buildings collapse when they are deformed up to the x mark. The earthquake energy absorbed is represented by the relation between the force (strength) & the deformation (toughness) and it’s the colored area under the curve.

For example, assuming that the area of the colored portion of the building A with larger strength but smaller toughness and the colored portion of the building B with lower strength and higher toughness are same, which means the energy absorbing capacity of both these buildings are the same. Therefore, the seismic performance of the two buildings can be regarded as the same. Based on this viewpoint, the seismic performance of the building can be represented by a simple index called Is value.



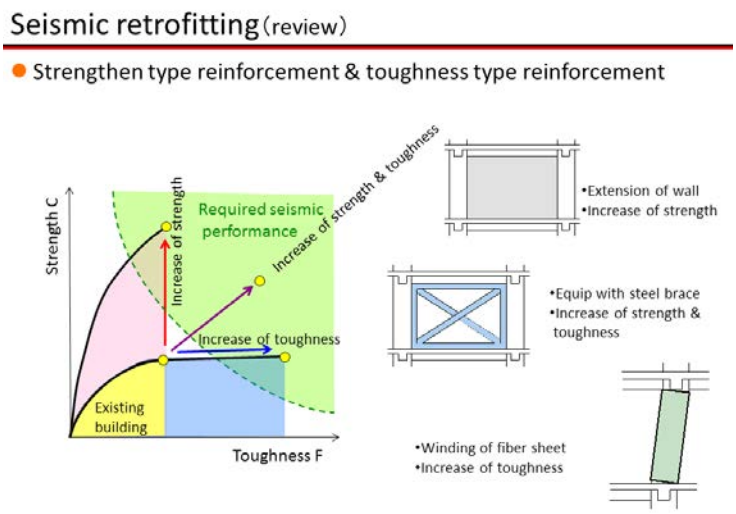
In the case of a reinforced concrete structure, I will show the seismic performance of buildings judged by seismic diagnosis.

First, the structural seismic index Is value is used as an indicator of seismic resistance of the building. The Is value is calculated from the above equation, where the strength index C is the strength of the building, the toughness index F is an index showing the tenaciousness of the building, and Is is obtained by multiplying them. In addition, apart from these indexes, correction coefficient , shape index which is a reduction coefficient considering the irregularity of the building (if the building is rectangular, L-shaped, or the wall is biased on one side of the building) , and there are time deterioration index which is an aging indicator (building years and the presence or absence of cracks) which are reduction factors considering aging of the building. These will also be multiplied.

This Is value is a numerical value of the performance up to the point where the building is broken as shown in the figure on the right, and this value evaluates whether the building will collapse or not. In other words, when an earthquake of certain size occurs, building may not collapse but it could be damaged.

The figure on the right compares the secondary diagnosis results of the existing reinforced concrete buildings that have not yet experienced the earthquake, with the building that suffered beyond medium damage in the 1968 Tokachi-offshore earthquake and in the 1978 Miyagi prefecture offshore earthquake. It can be seen that the building with the Is value of 0.6 or more is not damaged beyond medium damage. If the Is value gets lower the possibility of damage increases, and you can also notice that there are variations in the diagnosis result when the value is below 0.6.

For these reasons, the Is value, required by the building, is 0.6 or more as one of the guidelines.



Based on the Is value in the seismic diagnosis, unless the earthquake resistance performance required by existing buildings is satisfied, we will consider seismic retrofitting / reinforcement.

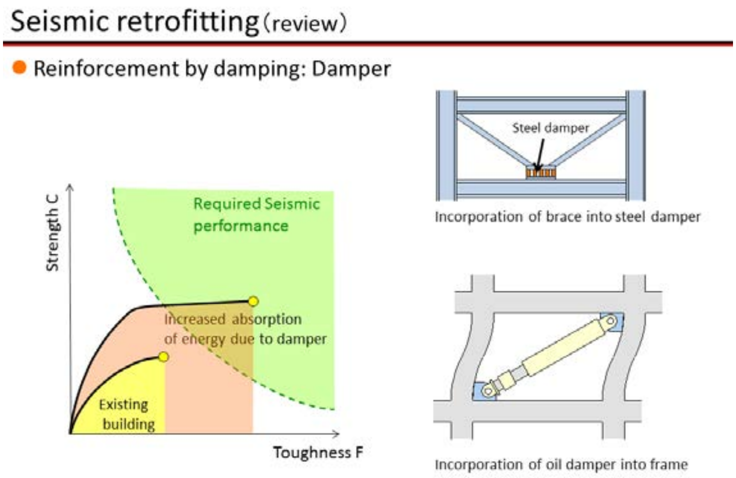
There are four ways to improve the seismic performance of existing buildings. These are strength type, toughness type, damping type and base isolation type.

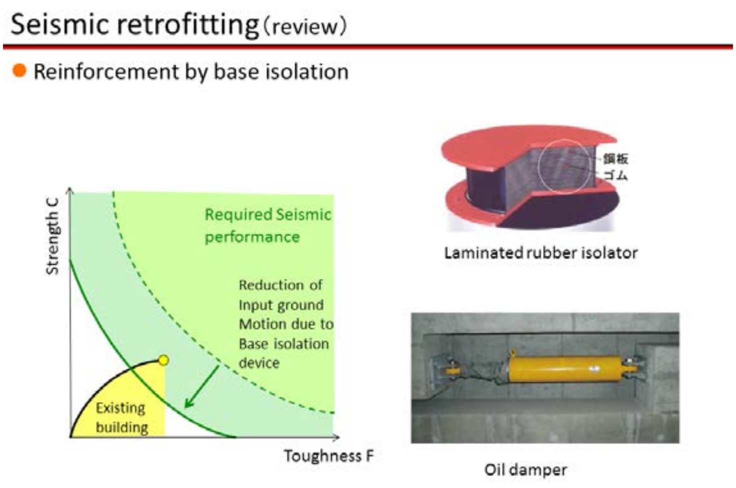
Strength type is a way to increase the strength of the existing building as shown in the figure. Toughness type is a method to increase the toughness of existing building as shown in the figure. In this way we can have the necessary earthquake resistance performance.

The damping reinforcement is a method of increasing the energy absorption performance of buildings by using seismic dampers.

As shown in the figure, the idea is to improve seismic performance by increasing the area obtained from the relationship between strength and toughness.

The seismic damper is installed with brace or frame.





Furthermore, the seismic isolation type is a method of weakening the seismic force transmitted from the ground by installing a seismic isolation device between the ground and the building.

A typical seismic isolation system consists of "isolator" and "damper", and "isolator" has the role of changing a shorter periodic seismic motion to a longer periodic seismic motion. On the other hand, "damper" is an energy absorbing device which has the role of stopping the deformation of the buildings.

INDEX: 日本免震構造協会
http://www.jssi.or.jp/menshin/m_kenchiku.html（2014.10)

Perspective of considering seismic retrofitting

- Fulfill required seismic performance

  Is ≧ Iso (Target value)

  Is : Seismic index of structure
  Iso : Seismic judgment index of structure

  Although the basic target value is set to be 0.6, it may be increased according to the Importance of the facility. (Shelter, earthquake countermeasure base, etc.)

- Cost

- Usability during construction
  - Usage of residence or office even during construction.
  - Problems of noise and dust
  - Temporary relocation is necessary for construction inside the building
  - Construction period should be shorter

- Ensuring of usability and functionality
  - Avoid blockage the opening by adding walls.
  - Function as a passage; lighting.

Based on the above concept of seismic retrofitting, what kind of seismic retrofitting will be suitable for a certain building depends on various considerations.

First of all, how far to improve seismic performance. It is necessary to make it larger than the structural seismic judgment index Iso, which is the target Is value of building after earthquake repair work. Generally, the structural earthquake resistance judgment index is set to 0.6, etc. However, the school facilities should be set at 0.7, evacuation centers and earthquake countermeasures bases will be increased by 1.25 times or 1.5 times taking the importance of facilities into account.

To do so, probably the most annoying problem is cost. It is also an option to choose an inexpensive construction method to reinforce at least against collapse. If the target service period is long, one option is to improve seismic performance so that it can be used continuously even after the earthquake.

Next is the usability during construction. Even during retrofitting work, it is often troublesome if you can not use it as a residence or office. In that case, if there is too much noise, dust and vibration, the living qualities will be impaired. So it is desirable to keep construction as small as possible. In addition, it is better to implement a shorter construction term , as temporary relocation is sometimes necessary. For this reason, there is a construction method that carries out seismic retrofitting only on the outside of the building.

Finally usability, functionality must be insured. For example, the reinforcement method like to add walls can improve strength at a relatively low price, but it will close the opening. As a result, the function as a passageway and lighting are disturbed. That's why, we've to consider selecting other construction methods.

Here, we summarized the method of seismic retrofitting for buildings other than wooden houses such as RC structures and Steel structures.

Since each construction method has its features, the construction method to be adopted based on advantages & disadvantages.

Types of Seismic retrofitting

- RC Structure & Steel Structure (excluding wooden house) 1

Types	Reinforced portion	Main characteristics	Method of construction, Materials
Expansion of RC wall	Frame	•Increase of strength & stiffness •Closure of opening	Cast in site wall (anchor or no anchor) Precast
Boost of RC Wall	Wall	•Increase of strength & stiffness	
Brace	Frame	•Increase of strength, stiffness & toughness •Lighting, Securing passage	Steel brace Concrete brace
Winding of steel sheet	Column	•Increase of toughness	
Continuous fiber winding	Column	•Increase of toughness •Simplicity of construction as no use of heavy machinery	Carbon fiber Polyamide fiber Polyester fiber
Expansion of sleeve wall	Column	•Increase of strength & toughness	
Newly built structural slit	Column	•Increase of toughness	

Types of Seismic retrofitting

- RC Structure & Steel Structure (excluding wooden house) 2

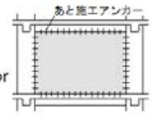
Types	Reinforced portion	Main Characteristics	Method of construction, Materials
External reinforcement	Frame	Increase of strength & stiffness Retrofitting while using the residence.	Wall Brace Frame
Buttress reinforcement	Frame	Increase of strength & stiffness Retrofitting while using the residence Need space outside	
Base isolation	Building	Decrease of Seismic motion.	Natural rubber type laminated rubber Sliding bearing Rolling bearing
Seismic mitigation damper	Frame	Increase of energy absorption	Viscoelastic damper Friction damper Low yield point steel damper

Expansion of RC Wall

•Increased RC wall to existing frame to improve stiffness & strength
•Might close the openings.
•Compared to other construction methods, strength is ensured through relatively inexpensive way.

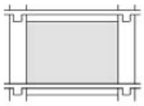
- Seismic retrofitted wall with anchor

General construction method to join frame work by post installed anchor.



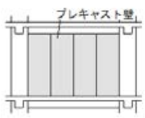
- Seismic retrofitted wall without anchor

As post installed anchor wasn't used, vibration and noise are small (adhesive bonding by epoxy resin etc.)



- Precast reinforced wall

No need to cast concrete in site
Shorter construction period



From here on, we will discuss compactly about seismic retrofitting method.

This is the reinforcement method by adding the RC wall. In this method we increase the stiffness and strength by adding RC wall in the existing frame as shown in the picture. Compared with other construction methods, it is characterized by being able to secure strength at a relatively low price. There are several types of this construction method. In general, in the seismic retrofitted wall with post installed anchor, existing frame is joined by using anchor. The wall part is cast in the site. In this case, problems such as vibration and noise due to connecting anchor to the wall will emerge.

As a construction method to mitigate the problem, there is a non-anchor seismic reinforced wall construction method. As a replacement of anchor,adhesive bonding such as epoxy resin etc. are used. In addition, there is a precast reinforced wall reinforcement, which is a method of manufacturing wall panels at the factory and then attaching them to existing frames. There is no need to cast concrete at the site. there is also a merit, and that is the construction period can be shortened.

This is brace reinforcement. By attaching steel brace and concrete brace to existing frame, it is possible to improve stiffness, strength and toughness. Additionally, it is possible to secure lighting and ventilation characteristics unlike the addition of RC walls which completely block the opening. The shape of the brace is X, V, etc. The mansard type brace can secure a passage through it as shown in the figure below on the left.

Also, with the addition of RC walls, there are anchor installed RC walls and non anchor RC walls.

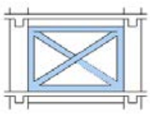
Expansion of braces

Adding brace to existing frame to increase the strength and stiffness.
Lighting & Ventilation are secured.

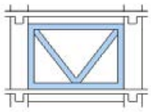
Retrofitted by V shaped steel brace

Retrofitted by Mansard shaped steel brace

- X shape brace

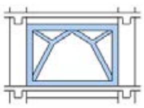


- V shape brace

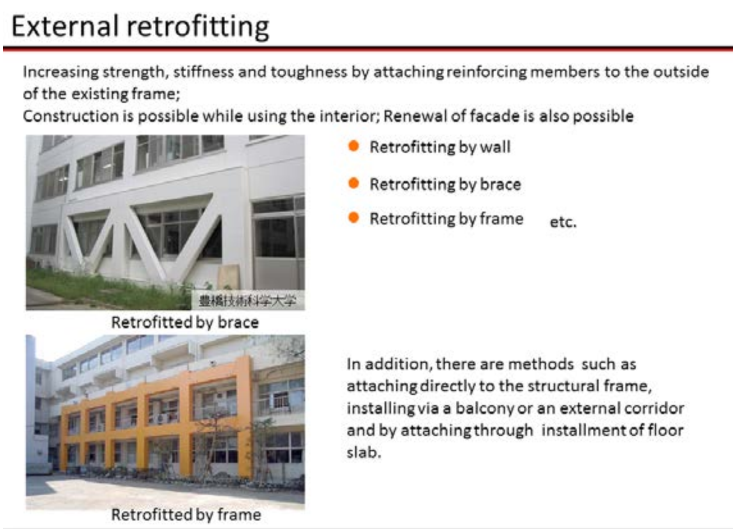


- Mansard brace

Opening could be secured.



Photo：文部科学省　耐震補強工法事例集



Photo：文部科学省　耐震補強工法事例集

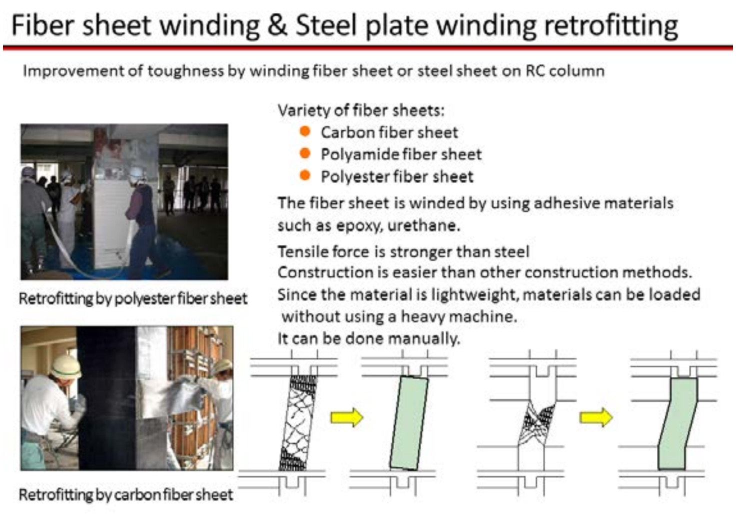
As the name suggests external reinforcement refers to a construction method that reinforces by attaching a reinforcing member to the outside of the building .

The main characteristic is that construction can be done while using the interior because of the method of attaching the reinforcing member to the outside of the building. There are types of reinforcing elements such as wall, brace, frame, and in the case of retrofitting by frame , the window space can be secured as shown in the lower left figure. Residence area such as housing complex or apartment, where lighting and ventilation is very important, in such places this retrofitting by frame is recommended. In addition, there are methods such as attaching directly to the structural frame, installing via a balcony or an external corridor and by attaching through installment of floor slab.

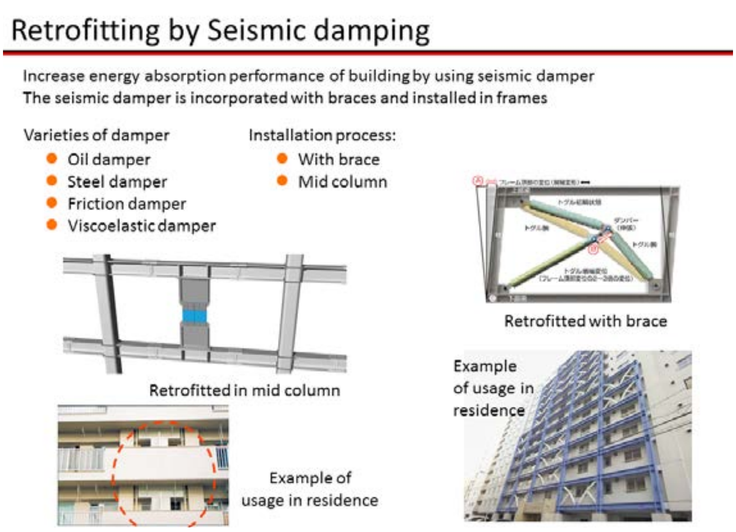
This is retrofitting by fiber sheet winding & steel plate winding. Unlike the retrofitting methods that raise the strength shown up to now, it is a construction method aimed at improving toughness, in particular.

As shown in the photograph, winding the fiber sheet or steel sheet around the RC column with an adhesive such as epoxy resin to bond it. If an excessive force (deformation) is applied to the column, there is a possibility that brittle shear failure may occur and support to the upper floor may fail. It is a method for improving toughness by winding a fiber sheet around column and restraining it from being damaged. As this material is lightweight, it can be carried in without heavy machinery and construction can be done manually.

So it can be said that construction is easy and inexpensive compared to other construction methods.



Photo：繊維補修補強協会：http://www.fir-st.com/index.html（2014.10）



As mentioned above, seismic retrofitting by the seismic isolation system is a method of absorbing energy by a damping control system such as a damper and reducing shaking of the entire building during the earthquake.

Dampers are installed in mid columns or incorporated with braces as shown in the figures, and they can be attached inside or outside the building.

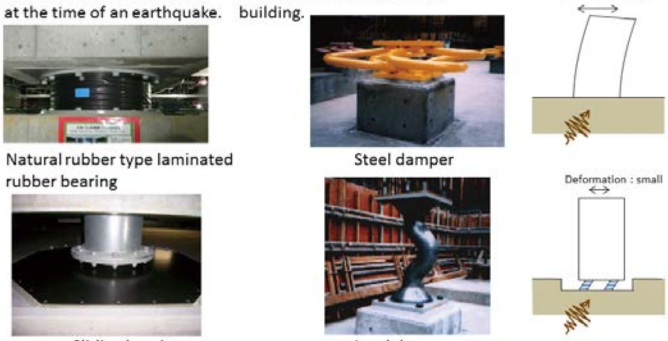
Figure：飛島建設
https://www.tobishima.co.jp/technology/architecture/seishin_index.html（2014.10）

Retrofitting by Base Isolation

By installing a seismic isolation device between the ground and the building, seismic force transmitted from the ground can be reduced largely.
The isolation device consists of an isolator (bearing) and a damper.

The isolator supports the building and moves it slowly at the time of an earthquake.

The damper works to quickly stop the continuous shake of the building.



Photo：日本免震構造協会　http://www.jssi.or.jp/menshin/m_kenchiku.html（2014.10）

Seismic retrofitting using a seismic isolation device is a method of weakening the seismic force transmitted from the ground by installing a seismic isolation device between the ground and the building.

A typical seismic isolation system consists of "isolator" and "damper", and the "isolator" has the role of changing a short period of seismic shake to a long period. And the "damper" is an energy absorbing device which works swiftly to mitigate buildings shaking. Although seismic retrofitting by base isolation equipment has cases such as Tokyo station building and Nagoya city office, but still they are just handful. The reasons for this are the price of the seismic isolation device, the necessity of the isolation pit (such as the basement floor) where the isolation device is placed, and the high cost due to the necessity of plumbing facility that can follow the large deformation.

There are various shapes and conditions in the buildings, and there are many ways of retrofitting in compliance with those shapes & conditions. The cost may not be said unconditionally, but anyway we will introduce some modification examples.

This is a construction method which adopts the external frame construction method which can do construction while using the interior and does not impair the functions of the passage and the lighting property of the window.

Index：愛知建築地震災害軽減システム研究協議会：耐震改修事例集
http://www.aichi-gensai.jp/　（2014.10）

Example of Retrofitting: Case 1

● Building overview

Structure: RC structure
Scale: 5 story
Built: 1970

● Construction overview

Cost: Approx. 20 million yen
Period: 4 months
Construction: Yahagi Engineering

● Construction method overview

Retrofitting by external frame (CESRet method)
Column 10 pieces (5 facades)

● Is value before and after retrofitting (X direction)

Story	Before	After
5	1.35	1.35
4	0.76	0.76
3	0.69	0.69
2	0.54	0.68
1	0.46	0.65

Ensure entrance　　Protect aesthetic view

Example of Retrofitting : Case 2

● Building overview

Structure: RC structure
Scale: 3 story
Built: 1965

● Construction overview

Cost: approx. 13 million yen
Period: approx. 9 months
Construction: Yahagi Engineering

● Construction method overview

Retrofitting by external frame (CESRet method)
Column 4 pieces (2 façades)

● Is value before and after retrofitting (X direction)

story	Before	After
3	1.68	1.68
2	1.31	1.31
1	0.41	0.74

Securing entrance and protecting aesthetic view

Similarly, this is a construction method that can be executed while using the interior such as adopting an external frame construction method that does not impair the function of the passage and the lighting property of the window.

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http://www.aichi-gensai.jp/　（2014.10）

Example of Retrofitting : Case 3

● Building overview

Structure: SRC structure
Scale: 10 story
Built: 1974

● Construction overview

Cost : Appro. 2 hundred 40 million yen
Period: approx. 7 months
Construction: Yahagi Engineering

● Construction method overview

Retrofitting by external frame
(Frame type pit column method)
Column 128 pieces

● Is value before and after retrofitting(South-west direction)

story	Before	After
5	0.46	0.87
4	0.43	0.85
3	0.45	0.78
2	0.41	0.77
1	0.37	0.63


Before retrofitting


After retrofitting

This is an example of retrofitting of pretty large scale building.

Index：愛知建築地震災害軽減システム研究協議会　耐震改修事例集
http://www.aichi-gensai.jp/ （2014.10）

There are various kinds of construction methods. It's necessary to pick the right method so that it doesn't impair the functionality and aesthetic appearance of the building.

Index：愛知建築地震災害軽減システム研究協議会　耐震改修事例集
http://www.aichi-gensai.jp/ （2014.10）

Example of Retrofitting : Case 4

● Building overview

Structure: RC structure
Scale: 14 story
Built: 1962

● Construction overview

Cost: Approx. 630 million yen
Period: Approx. 1 yr 2 months
Construction : Takenaka Corporation

● Construction method overview

Expansion of RC earthquake resistant wall
(Adhesion method, add-on method)
Expansion of steel brace
Expansion of latticed steel sheet panels
Expansion of SRC external frame
Column RC winding stand
Structure slit

● Is value before and after retrofitting (South west direction)

Story	Before	After
5	0.46	0.87
4	0.43	0.85
3	0.45	0.78
2	0.41	0.77
1	0.37	0.63


Facade

Latticed steel sheet panels

Expansion of RC earthquake resistant wall

Types of Seismic Retrofitting

● Long span structures（Gymnasiums, factories etc）, Steel structures

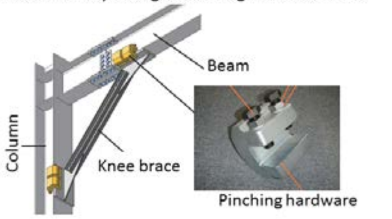
Types	Reinforced portion	Main Characteristics	Method of construction, Materials
Reinforcement by brace	Frame	Increase of strength, toughness and stiffness	Steel brace Concrete base
Horizontal brace retrofitting	Roof	Increase of strength & stiffness Transmission of horizontal forces through roof	Steel brace
Rib plate retrofitting	Beam to column joint	Reinforcement of beam to column joint & column to column joint	
Knee brace retrofitting			
Plate retrofitting			
Retrofitting by base wrapping concrete	Column base	Retrofitting of column base	
Retrofitting of ceiling	Ceiling	Prevention of fall or damage of ceiling	Reinforcement of the ceiling hanger

Here, we summarized the construction method of seismic retrofitting for large span structures such as gymnasiums, factories and Steel structures.

Retrofitting of Beam to Column joint

By raising the stiffness and strength around the column joint by using steel plates and knee braces, it is possible to prevent breakage of the welded joint around the beam joint and its surroundings.
As a result, the seismic performance is determined by strength and toughness of another member

Retrofitting by Rib plate



Retrofitting by Knee brace of Pinching joint

For joining retrofitting members, welding and bolt are used.
At sites where fire can not be used, pinching joint may be adopted instead of welding.

Photo：文部科学省：耐震補強早わかり　地震に負けない学校施設ー耐震補強事例集
Figure：矢作建設工業：http://www.yahagi.co.jp/solution/resist/achieve.html（2014.10）

Here we show the retrofitting method of the column to beam connection in Steel structure.

This is a method of raising the stiffness and strength by using a steel plate (rib plate) or knee brace for beam to column joint like this image. By retrofitting, it is possible to prevent breakage of the welding joint around the beam joint and its surroundings. By improving the seismic performance such as strength and toughness of members, in a whole the seismic performance of the entire building will be improved.

Welding and bolt joining are common and inexpensive for joining of reinforcing members. But in the sites where fire is prohibited, or bolt holes are difficult to open because of vibration, pinching joints by using pinching hardware such as the one shown on the right are adopted.

In buildings with large spans like the gymnasium, there are cases where the roof is reinforced, and the strength and stiffness are improved by the horizontal brace.

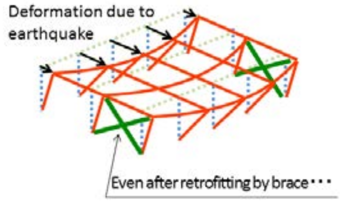
This is to suppress the deformation and damage of the roof at the time of earthquake and to prevent the fall of the ceiling. Also, if the stiffness of the roof is low, the center of the building will deform larger than the end, as shown in the right figure.

In this case, even if retrofitted with walls and braces at the end part of building, the retrofitting member is not effectively working against the seismic forces. In such case reinforcement may become necessary.

Retrofitting of roof by horizontal brace

Improve strength and stiffness by horizontal bracing of the roof
In addition to suppressing deformation and damage of the roof during earthquakes, it prevents the ceiling from falling.
Transmit the seismic force to the brace or extension wall through the roof.

Retrofitting of roof surface by horizontal bracing



If the horizontal stiffness of the roof is small, a large deformation happens in the center part

（左写真）文部科学省：耐震補強早わかり　地震に負けない学校施設ー耐震補強事例集

Types of Seismic Retrofitting

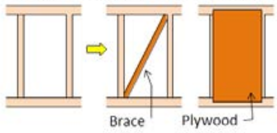
Here, we have summarized the method of retrofitting for wooden houses.

● Wooden house

Types	Retrofitting portion	Main Characteristics	Construction method, Materials
Expansion of load bearing wall		Increase of strength and stiffness	Structural plywood
Expansion of brace		Increase of strength and stiffness	Wooden brace Metal brace
External Retrofitting		Increase of strength and stiffness Using interior while retrofitting	Brace Frame
Retrofitting of base	Base	Making base stronger	RC beam extension
Retrofitting of floor (2 story or above)	Floor	The whole building is made to be earthquake resistant	Brace, Angle brace beams
Retrofitting of joint	Joint	Prevent collapse of building due to coming off beam to column joints	Joint hardware
Making roof lighter	Roof	By reducing weight of roof, seismic force can be reduced	
Base Isolator	Building	Reduction of Seismic force	

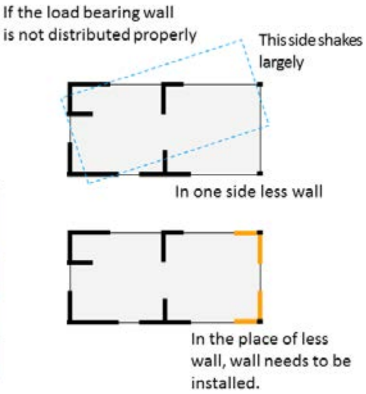
Retrofitting by Load Bearing Wall

Increase of strength of building through load bearing wall
Load bearing wall: A load bearing wall refers to a wall with diagonally installed braces within the columns and walls with structural plywood hammered with nails.



Examples of wall standard yield strength used in general diagnostic methods

Types	Standard wall resistance (kN/m)
Clay wall (Paint thickness40~50mm)	1.5
Brace(15×90mm, Fixed with metal)	2.4
Structural plywood	5.2



Many of the buildings collapsed by the earthquake are said to have a small amount of load bearing walls. First of all, increasing the load bearing wall and increasing the resistance to earthquake shaking becomes the basis of earthquake resistant reinforcement.

A load bearing wall refers to a wall with diagonally installed braces within the columns and walls with structural plywood hammered with nails.

It shows an example of a wall with standard yield strength used in the general diagnostic method. The standard wall strength is the strength of a wall of 1 m of length. It is a value that varies depending on the thickness and mounting conditions. The value is 1.5 for clay wall, 2.4 for the brace and 5.2 for the structural plywood. Retrofitting method by reinforcement of structural plywood makes it easier to ensure strength comparatively.

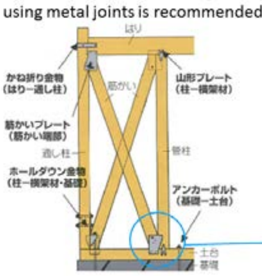
However, even if the amount of wall is sufficient, if the position of the wall is biased towards one side of the building or not well-balanced, it will not be able to hold on strong against earthquake. For example, if you have a large opening on the south or may not place a wall because of parking space, the building will be twisted, and deform in the less wall part resulting in collapse.

For that reason, we need to install a load bearing wall in the zone of few walls.

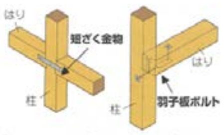
Although we mentioned the retrofitting method by using the load bearing wall, in order to make effective use of columns, load bearing walls as members resisting the seismic force , it is necessary to make the joint part secured. Unless the joints are solid, there is a risk that the braces and columns may come off resulting in building collapse due to seismic force.

Retrofitting by Metal Joint

In order to make effective use of load bearing walls, columns etc. as members of resisting the seismic force, it is necessary to make the joint part secure.
For that purpose retrofitting of the joints of the braces, beams, columns and foundation using metal joints is recommended.



Example of brace joining on load-bearing wall



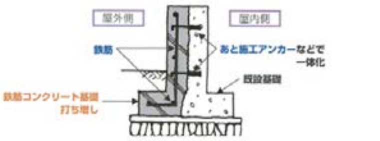
Side beam to column metal joint retrofitting

Brace end & Column base metal joint retrofitting

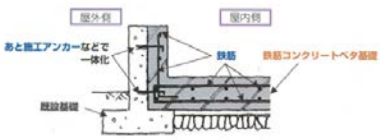
(Index) 豊橋市：命を守る家づくり～木造住宅の耐震対策のすすめ～

Retrofitting of Base

In order to make effective use of load bearing walls, columns, etc. as members resisting seismic forces, it is necessary to make the base firm too.
For that purpose we make expansion of reinforced concrete fabric base, mat foundation etc.



Retrofitting by reinforced concrete fabric base



Retrofitting by mat foundation

Figure：豊橋市　命を守る家づくり～木造住宅の耐震対策のすすめ～
Photo：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

The foundation of wooden houses is also an important structural element. Like the metal joints, for the load bearing walls to work effectively, the foundation must also be solid.

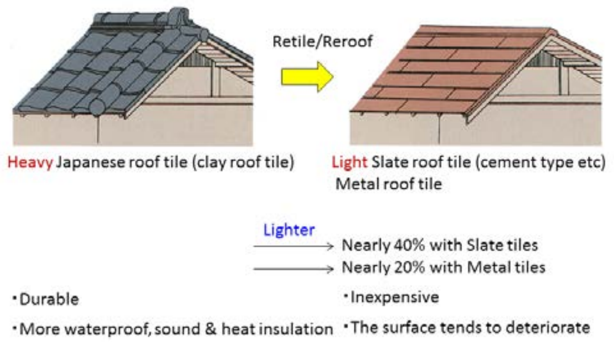
If there is no reinforcing bars in the existing base or if there are large cracks, the base may be broken and the upper building may collapse. In such case, we will build a base with new reinforcing bars and make the foundation strong.

The increase of only width to the existing fabric foundation below the base is considered a type of foundation.

Adding that, the other type is called solid foundation, and that is under the ground floor solid foundation of reinforced concrete.

Making Roof Lighter

By reroofing the roof tile to a light one to lighten the weight so that the seismic force gets reduced, Seismic resistance performance is improved.



Figure：豊橋市　命を守る家づくり～木造住宅の耐震対策のすすめ～

The heavier the house, the heavier the seismic force will be. This is because weight × acceleration due to earthquake motion = horizontal force acting on the building, Therefore, the lighter the weight the smaller the seismic force the building will be. That is why, while retrofitting, when roof is covered with clay roof tiles, one of the recommendations is that to reduce the seismic force by changing heavy tiles to light tiles.

By reducing the weight of the roof, it is possible to improve seismic performance or have to reduce the amount of walls required.

Cost of Seismic Retrofitting (Wooden house)

This shows the seismic retrofitting cost of wooden houses.

Seismic retrofitting construction costs will vary depending on the size and condition of the housing.

The cost ranges from less than 1 million yen to about 5 million yen, but the most construction cost is 1 to 1.5 million yen. In addition, more than half of the works are done at about 1.87 million yen or less.

If the structure seismic resistance index Is value is considerably small, there is a possibility that the cost will be higher in order to satisfy the new earthquake resistance criteria. However, instead of doing seismic retrofitting at once, it is better to proceed step by step. For example, if we have weak buildings with an Is value of about 0.2, we first set the Is value to 0.7 by installing load-bearing walls etc. As next step of retrofitting, we re-roofed the roof and set the Is value to 1.2. We should approach forward to make buildings earthquake resistant even though we have our limitations, as our small contributions can lead us to reducing the loss when earthquake occurs.

Estimated cost for each seismic retrofitting construction

- **Load bearing wall (Exterior wall)**
  - 130～150 thousand yen/Width 910mm
  - Average 147 thousand yen/width 910mm
- **Load bearing wall (Interior wall)**
  - 90～120 thousand yen/Width 910mm
  - Average 121 thousand yen/Width 910mm (Interior)
  - Average 107 thousand yen/Width 910mm (Closet)
- **Roof**
  - 15～20 thousand yen/m²
  - Average18 thousand yen/m² (Steel sheet tile)
  - Average 15 thousand yen/m² (Slate sheet tile)
- **Base**
  - 40～55 thousand yen/m
  - Average 44 thousand yen/m (Additional)
  - Average 53 thousand yen/m (Newly built)
- **Joint**
  - 40～60 thousand yen/4 places
  - Average 50 thousand yen/4 places

Indicates the estimated cost for each seismic retrofitting construction.

When seismic retrofitting is concurrently performed with reforming, the cost of seismic retrofitting itself tends to be somewhat cheaper.

Example of Retrofitting: Case 1

● Method of Retrofitting

Retrofitting of existing wall (Earthquake resistant wall) 23 places

● Building overview

Number of stories: 2 story
1st floor: approx. 62m²
2nd floor: approx. 39m²
Built: 1981

● Is value before and after retrofitting

	1st floor X dir.	1st floor Y dir.	2nd floor X dir.	2nd floor Y dir.
Before	0.58	0.68		
After	1.03	1.24		

● Construction cost

Retrofitting of base crack	180,000	
Retrofitting of wall	1,776,000	23 places
Various expenses	156,000	
Total cost	2,112,000	

＊工事費用は参考としてください

It is an example of seismic retrofitting mainly by wall reinforcement.

Index：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

It's an example of retrofitting of base.

Index：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

Example of Retrofitting : Case 2

● Method of retrofitting

Retrofitting of existing wall (Load bearing wall) 2 places

Existing base retrofitting 32m

● Building overview

Number of stories: 2story
1st floor: approx. 53m²
2nd floor: approx. 27m²
Built: 1978

● Is value before and after retrofitting

	1st floor X dir.	1st floor Y dir.	2nd floor X dir.	2nd floor Y dir.
Before	0.47	0.80	0.70	1.09
After	1.06	1.27	1.01	1.57

● Construction cost

Base retrofitting	1,470,000	32m
Wall retrofitting	223,000	2 places
Various expenses	84,000	
Total cost	1,777,000	

＊工事費用は参考としてください

Example of Retrofitting: Case 3

● Retrofitting method

Retrofitting of existing wall (Load bearing wall) 30 places
Lightening of roof 160m²

● Building overview

Number of stories: 2 story
1st floor: Approx. 108m²
2nd floor: Approx. 47m²
Built: 1972

● Is value before and after retrofitting

	1st floor X dir.	1st floor Y dir.	2nd floor X dir.	2nd floor Y dir.
Before	0.40	0.40		
After	1.23	1.39	2.67	3.93

● Construction cost

Base retrofitting	2,050,000	160m²
Wall retrofitting	4,145,000	30 places
Various expenses	210,000	
Total cost	6,405,000	

＊工事費用は参考としてください

It is an example where seismic retrofitting is carried out mainly by basic reinforcement and weight reduction of the roof.

Here we have retrofitted roof from Japanese roof tiles (roofing) to flat roof slate roofing.

Index：滋賀県　木造住宅耐震改修事例集～住まいを強くする～

Information on Seismic Retrofitting

- Ministry of Education

  Ministry of Education homepage
  「Example of Seismic retrofitting」,
  「耐震補強早わかり　地震に負けない学校施設ー耐震補強事例集」.
  学校施設の補強例が掲載．全体工事費，補強部分の概算も記載.

- Aichi Earthquake Disaster Reduction System Research Council of Building

  http://www.aichi-gensai.jp/　　(2014.10)

  「 Low cost seismic retrofitting guidance for Wooden houses 」

- Building Disaster Prevention Association

  http://www.kenchiku-bosai.or.jp/　　(2014.10)

  「誰でもできるわが家の耐震診断」

Other information

- Aichi Prefecture Disaster Management Bureau: Aichi Prefecture Disaster Learning System

  http://www.quake-learning.pref.aichi.jp/　　(2014.10)

This is Aichi Prefecture disaster prevention learning system.

In the disaster prevention map, when the seismic motion of past large scale earthquake is input, you can see the seismic intensity distribution, liquefaction risk, tsunami flooding depth, etc. corresponding to Aichi prefecture.

In the "Building collapse simulator", if you enter simple information on a wooden two-story house, you will see animation whether it will collapse or not, in occurrence of earthquake.

English

つながる教材

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Differences Between Tsunamis and Storm Surges (1)

	Prediction	Protective Structures	Evacuation
Tsunami	Earthquakes are unpredictable. However, it may take time for a tsunami to reach the bay (**about 1 hour in the Mikawa Bay**).	Since it follows an earthquake, structures (such as levees and water gates, drainage pumps, their management structures, etc.) may not be functional.	Depending on the scale of road and building damage
Storm Surge	Typhoon's path and scale can be estimated to a certain accuracy.	Possible if the storm surge is predictable. However, in case of heavy rain, it may lead to multiple disasters in addition to river overflow.	Depending on the scale of river overflow

- A tsunami is unpredictable because it is generated by an earthquake (also unpredictable). However, there is time to evacuate, since it takes time for a tsunami to roll across the ocean and to reach the coast. The issue when an earthquake occurs first is that protective structures may be deteriorated by the time a tsunami strikes the coast.

- A storm surge is caused by a typhoon. Thanks to the high accuracy of Japanese predictions, storm surges can be estimated to a certain accuracy (path and scale). Moreover, astronomical tides (high and low tides) predictions are also highly accurate, which makes it possible to know beforehand whether a storm surge will lead to other disasters. What matters is to know when a disaster such as heavy rain or floods due to typhoons, will occur.

- A tsunami is caused by a water level change due to seismic activity. Wave height increases as it reaches the coast (where water is shallow).

- A storm surge is caused by water suction accompanied by low atmospheric pressure due to a typhoon, and a strong wind drift (a movement downwind). These two effects are what make sea surface level rise abnormally.

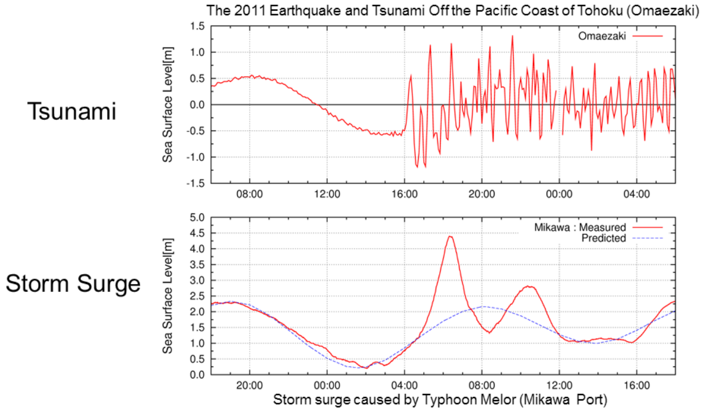
Both tsunamis and storm surges are dangerous when they strike the coast, since the quantity of water (≈ wave height) increases when it is displaced to shallow waters.

Differences Between Tsunamis and Storm Surges (2)

	Causes	Characteristics	Duration
Tsunami	Rise (or decline) in the sea level due to submarine earthquake → **Propagation of water level change**	Earthquakes are unpredictable. However, it may take time for a tsunami to reach the coast. Accompanied by earthquake damage	Up to 1 hour (but risk of multiple tsunamis)
Storm Surge	Low atmospheric pressure because of a typhoon (**suction effect**) and rise in the water level due to strong wind drift (**wind drift effect**)	Typhoon's path and scale can be estimated to a certain accuracy. Accompanied by high waves, floods, strong wind	Several hours

Both get stronger when they approach the coast (as water gets shallow).

Comparison of the Tsunami/Storm Surge Sea Level Change Over Time



- The cycle of one tsunami wave takes 10 minutes to 1 hour.

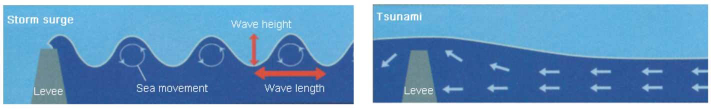
- The cycle of a storm surge depends on the wind speed of typhoon and takes several hours in most cases. The difference between the two is pretty clear, by comparing the sea level change over time. Since both were accompanied by the astronomical tide (sea level change = astronomical tide + (tsunami or storm surge)), tide level at that time had a big influence on whether disasters occurred and on the scale of those that did occur.

Waves we usually see at the sea travel in cycles that last from a few seconds to dozens of seconds. However, this cycle takes more than 10 minutes for a tsunami, which is a pretty long cycle. To be more precise, "a long cycle" refers to "a long wave length (the length of one wave)." Waves of both tsunamis and storm surges are said to be "long" because of their unusual length.

A normal wave measures between a few meters to a few hundred meters, whereas the wave of a tsunami can be measured in kilometers. Therefore, the waveform gradient (wave height/wave length) is extremely small, even for a tsunami of a few meters (for instance, if wave height H=10 m and wave length L=10 km, then H/L=0.001), so the water level will only rise a little (except for offshore tsunamis).

Differences Between a Tsunami and (Normal) Waves

- Differences between waves and a tsunami
  - Wave length　Waves of a few meters high cause a gentle wave
    A few m to hundreds of m / A few km to dozens or hundreds of km ↓
    Boats can **overcome** a tsunami
  - Movement
    Back and forth movement due to water level change /
    Water mass movement, **current**
  - Energy
    Wave energy, **repetitiveness** / Hydrodynamic energy due to the current, **uninterrupted movement** for some time

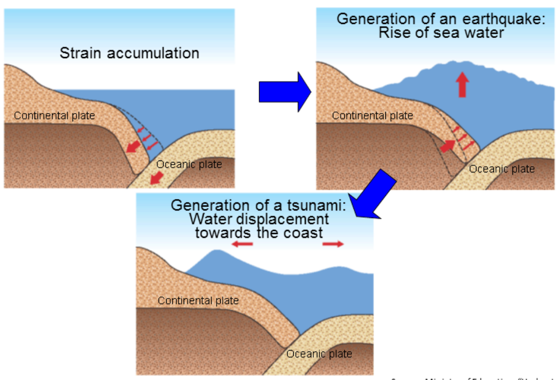


As far as water movement is concerned, normal waves usually go back and forth (which you can easily understand if you have ever bathed in the sea with a rubber ring). The cycle of a tsunami appears to be related to the same back and forth movement as normal waves, but its waves travel so far that what we can actually comprehend it is not its time scale (a few seconds to a few minutes or dozens of minutes), but the current caused by the movement of the water mass.

Normal waves usually dive into the surface sea and are not affected by the water mass, while during a tsunami, water is displaced from the surface to the bottom of the sea (since its strong energy reaches deep waters).

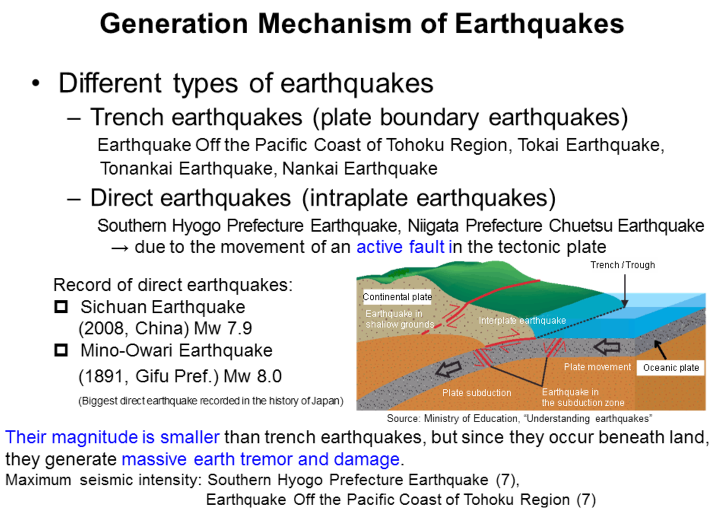
Learn more about: **Tsunamis**

- Generation mechanism



Source: Ministry of Education, "Understanding earthquakes"

As most of you may already know, a tsunami is the displacement of a substantial volume of water attributed to an earthquake at the bottom of the sea, increasing water level, which causes damage when striking the coast.



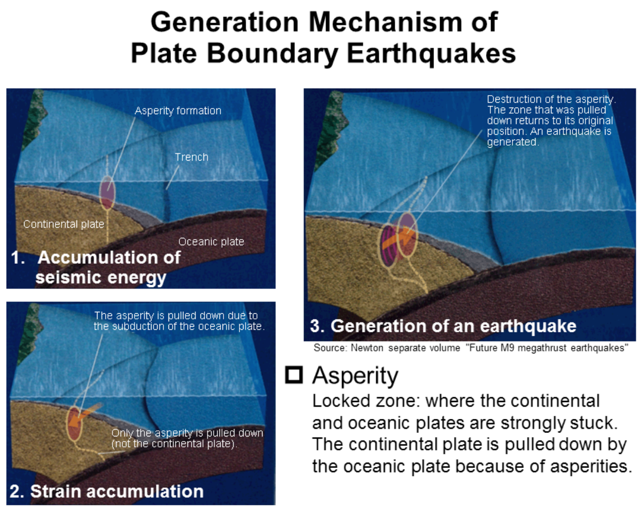
There are two types of earthquakes: plate boundary earthquakes generated at the boundary of continental plates, and intraplate earthquakes generated away from plate boundaries.

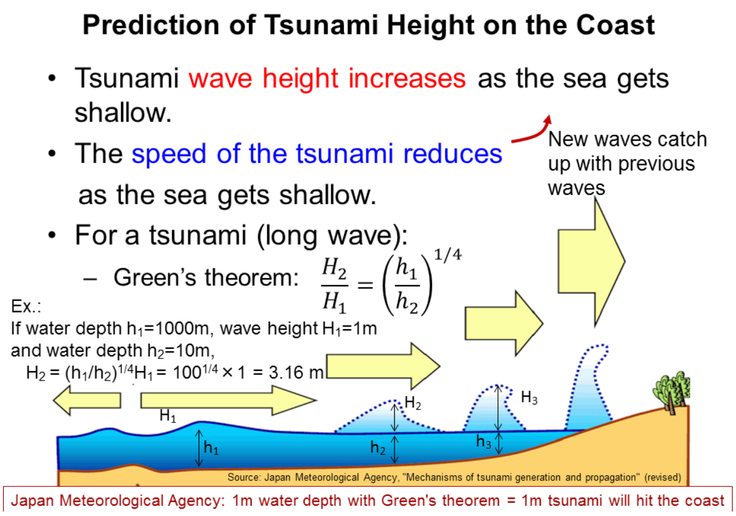
Plate boundary earthquakes are also called trench earthquakes since the deep trench at the bottom of the ocean, such as the Japan Trench, is located right next to the continental plate (hence forming a boundary).

Intraplate earthquakes are generated in a relatively shallow area, right under the land we live on, and are also called direct earthquakes.

Plate boundaries are rather far away from the continent, so the seismic intensity (earth tremor) we feel on the ground is rather small, as opposed to direct earthquakes, because they are generated right under our feet. This is why damage caused by the tremor is important. In the event of a trench earthquake leading to a tsunami, its magnitude is bigger than the earth tremor, which I will talk about later on.

"Asperities"…This expression tends to be commonly used nowadays by the Central Disaster Management Council in its presentations concerning the hypocenter of Nankai megathrust earthquakes. Also called a "locked zone", it refers to the area where plates are strongly stuck to another. It does not merely make the continental plate curve down beneath the oceanic plate, since it also generates earthquakes that may differ depending on the size and geographical distribution of such asperities. The Central Disaster Management Council take the position of these asperities into consideration in the epicenter model.

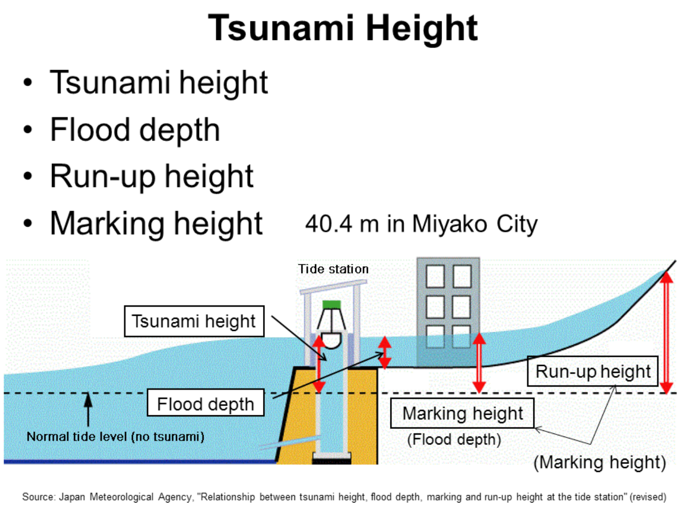




The particularity of a tsunami is that it gets higher as the sea gets shallow, while wave speed decreases. As the sea gets shallow, wave length decreases: at a specific point, the quantity of water carried in one wave equals the one of the sea, boosting tsunami height.

The change in tsunami wave height can be roughly estimated using Green's theorem. the change in wave height is given by the water depth ratio raised to the 1/4th power. Therefore, tsunami gets rapidly higher as the water depth decreases.

The formula to measure the speed C of the tsunami (as well as storm surge) wave length is $C = \sqrt{gh}$ (g: gravitational acceleration, h: water depth). Water depth h and speed C decrease while the wave approaches the coast. Therefore, since waves that follow a tsunami (waves going in the same direction as the tsunami after it approaches the coast) travel faster, they catch up with previous waves, increasing wave height.



Some of the expressions commonly used to refer to tsunami height are:

- Tsunami height (wave height)
- Flood depth
- Run-up height
- Marking height

etc.

Sometimes, however, these expressions are mixed up.

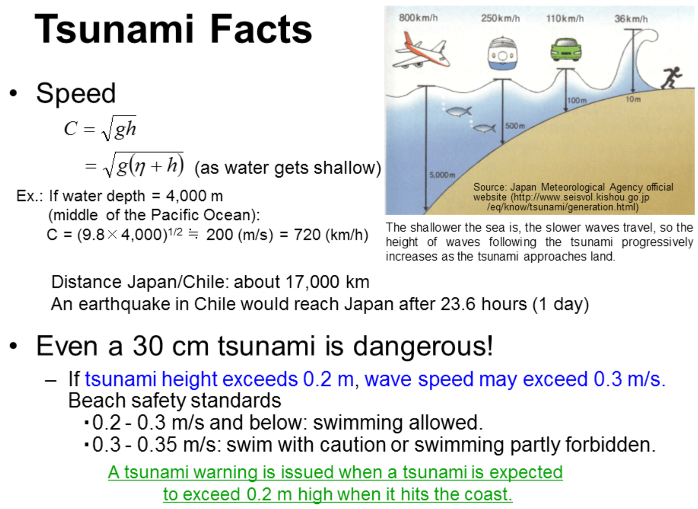
This is often the case with “tsunami height”, as it can be used to refer to several concepts.

For instance, we often hear on the news about “a 30 m tsunami,” however this is not referring to the “wave height” (from the bottom to the top of a wave), but to the run-up or marking height.

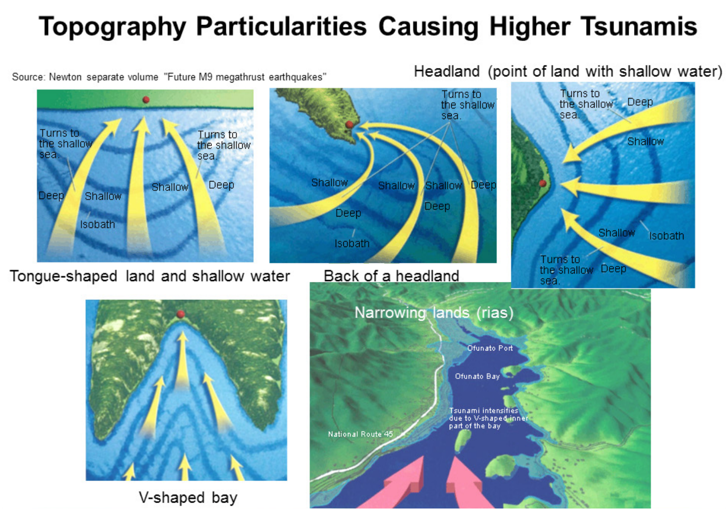
This is why you have to be particularly careful when you hear the expression “tsunami height”.

As I have already said, the formula to calculate the speed C of a tsunami is $C=\sqrt{gh}$. A tsunami in the Pacific Ocean, which is about 4000 m deep, would propagate at 200 m/s = 720 km/h, an average speed. This is close to the speed of a jet. Therefore, supposing there was an earthquake on the other side of the planet, in Chile, located 17,000 km from Japan, it would reach the coast after 23.6 hours (about one day). If this earthquake generates a tsunami, this could be even 30 cm high.

Since tsunami is a long wave with a current traveling both at the surface of the water and at the bottom of the sea, this 30 cm tsunami could be compared to a 30 cm deep current (river).



In general, when a tsunami exceeds 20 cm high, its speed goes beyond 30 cm/s, thus having a high potential for putting lives at risk.



The propagation and form of a tsunami differ depending on the topography of the coast it is traveling to.

Tsunamis as well as normal waves travel while forming right angles with isobath (a line that connects all points having the same depth below a water surface, the same altitude on a topographic map, the same atmospheric pressure on a weather map). This is why the energy of a tsunami tends to concentrate on shallow grounds and headlands (= higher waves).

Besides, a tsunami that hits the mouth of a bay where land narrows, such as V-shaped bays and rias, concentrates its energy on the inner part of the bay, which causes considerable damage.

Tsunamis Hitting Ports and Coastal Areas

- Destructive breaking wave
  - Stronger wave power applied to structures

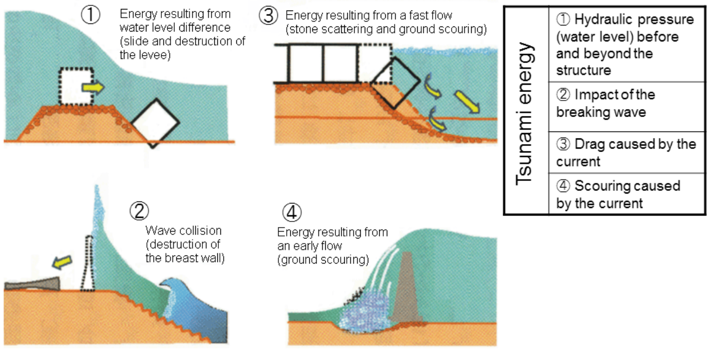
- Rivers flowing upstream (in waves or one breaking wave)
  - More damage due to tsunami hitting inland areas, damage to river structures, levee damage and overflow
- Ports
  - More damage to port infrastructure, vibrations (wave height increase), more ship damage, and negative consequences on fishery

When a tsunami strikes the coast, the depth of the sea decreases so much it generates a destructive breaking wave. It is possible to design structures, such as seawalls, to be hit by normal waves, by considering hydrostatic pressure ($p=\rho gh$), which can only be determined by water depth. However, in the case of a destructive breaking wave, extra energy is deployed by the water mass when struck on the wall, leading to an increase in the amount of energy that hits the structure. This is why these structures face a greater risk of damage. Moreover, a tsunami may strike river estuaries, and hit inland areas by flowing upstream. Damage to ports is inevitable.

Therefore, tsunamis can cause several kinds of damage in coastal areas.

Protective Structures in Ports and Coastal Areas

- Potential damage to coastal disaster prevention structures



Source: JSCE Magazine, "Feature Issue on Disasters - Great East Japan Earthquake", July 2011

Many coastal structures are damaged by tsunamis, as was the case during the Great East Japan Earthquake. This damage can be divided into the 4 following patterns.

① Damage due to water level difference: when sea water overflows, the water level between the sea and land sides differ (sea side > land side), applying an excessive hydraulic pressure to structures, and damaging them.

② Damage due to wave impact: when the tsunami breaks onto structures, its water mass is applied on it, thus applying an excessive energy onto it (breaking wave pressure), and damaging these structures.

③ Damage due to drag: structures can be damaged (especially foundations) due to the powerful current accompanying a tsunami (speed and overflow).

④ Damage due to scouring: when sea water overflows, it generates a rapid current (supercritical flow) above structures which then falls down. Inland structure foundations end up scouring, damaging these structures (which frequently occurred during the Great East Japan Earthquake).

Relationship Between Magnitude M, Energy E and Tsunami Wave Height H

- $E = 10^{4.8+1.5M} = 10^{4.8} \cdot 10^{1.5M}$
- $M_t = \log_{10} H + \log_{10} D + 5.80$
  (D: propagation distance ≥ 100km)
- If magnitude M increases by 1 (ΔM=1), then energy E gets 32 times bigger ($10^{1.5\times\Delta M}$ times).
- If magnitude M_t increases by 0.3 (ΔM_t=0.3), then tsunami wave height H doubles ($10^{\Delta M}$ times).

Here are the formulas to determine the relationship between earthquake energy and magnitude on one hand, and tsunami wave height and magnitude (as well as propagation distance) on the other hand. To solve this equation briefly, when the magnitude increases by 1, the energy deployed by an earthquake gets 32 times bigger. If magnitude only increases by 0.3, the wave height of a tsunami caused by this earthquake would double.

In this slide, M_t refers to tsunami magnitude, a parameter indicating the scale of a tsunami. In the case of a distant tsunami, the earthquake magnitude M is roughly equal to the tsunami magnitude M_t.

Magnitude and earthquake energy, as well as the wave height of the tsunami the earthquake generates, do not have a linear relationship (that is to say, if one doubles, so does the other). Indeed, since they significantly increase compared to the rise in magnitude, it is important that everybody understands the level of danger through information given in news flashes mentioning earthquake magnitude.

Tsunami Damage

→ Mikawa Bay (from 4 m) → Ocean (from 32 m)

Wave Height (m)	1	2	4	8	16	32
Wooden houses	Partly destroyed		Entirely destroyed			
Stone houses	OK		(no data)	Entirely destroyed		
Ferroconcrete buildings	OK			(no data)		Entirely destroyed
Fishing boats		Some damage	50% damaged	100% damaged		
Protection forests	Minor damage, smaller tsunami, no floating debris		Some damage, no floating debris	Entirely destroyed, no use		
Shellfish culture			Some damage			
Coastal villages		Some damage	50% damaged	100% damaged		

Source: Shuto, 1993

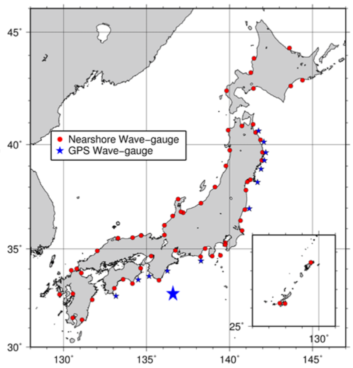
In 1993, Shuto and others established the correlation between tsunami wave height and damage done on houses and other structures, based on past surveys on tsunami damage. Furthermore, the Central Disaster Management Council recently released its tsunami predictions. In the event of a tsunami, a wave more than 20 m high is expected to hit the coast of the Aichi Prefecture, which should not exceed 4 m in the Mikawa Bay. When this kind of extremely high tsunami is predicted, considerable damage is to be expected, even in the Mikawa Bay.

The Ministry of Land, Infrastructure, Transport, and Tourism has created a wave information network called NOWPHAS (The Nationwide Ocean Wave information network for Ports and HArbourS) and installed a coastal wave monitoring system throughout Japan. Thanks to NOWPHAS, Japanese coasts are constantly monitored. Information obtained is posted on its official website as necessary. The GPS systems that were measuring waves on the coasts from the Aomori to the Fukushima Prefectures (located 100 to 400 m deep in the sea, 10 to 20 km off the coast) at the time of the 2011 tsunami monitored its shape, and transmitted important data, which helped analyzing the particularities of this tsunami and working on countermeasures.

Japanese Observation Network

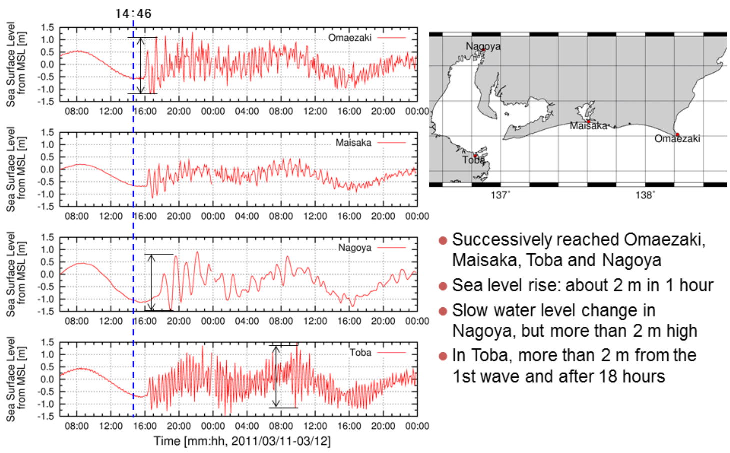
- NOWPHAS
  The Nationwide Ocean Wave information network for Ports and HArbourS
  http://nowphas.mlit.go.jp/index.html
  - Conducted by the Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport, and Tourism
  - Managed by the Port and Airport Research Institute
- Coastal wave monitoring, wave measurement by GPS
  - Understanding the particularities of the 2011 tsunami significantly contributes to future countermeasures

Installed in the Ise Bay since 2013



In June 2013, this monitoring system was installed off the mouth of the Ise Bay.

The 2011 Tsunami Observed in the Tokai Region

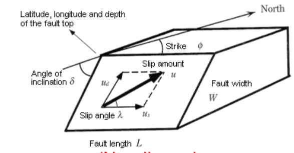


Let me now talk about the tsunami of March 11, 2011, as recorded by tide stations of the Tokai region. The first wave successively reached Omaezaki, Maisaka, Toba, and then Nagoya. In Omaezaki and Toba, two cities facing the ocean, a very small vibration was measured.

In Maisaka, a small fluctuation was observed since the tide station is installed in the Lake Hamana, but the water level clearly differed from the ordinary tide level. Even the Nagoya tide station, located in the innermost part of the Ise Bay, recorded a slow fluctuation, and the water level increased more than 2 m higher than usual. After one day, the water level was still high, indicating how serious the scale (energy) of this tsunami was.

How to Predict Tsunamis (Simulations)

- Fault model
  - Prediction of the strength and scope of ground fluctuation by applying the following parameters.
  - The sea level fluctuation it triggers is the first tsunami wave.



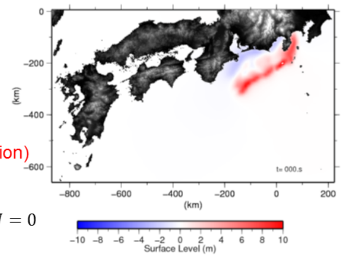
(Non-linear long wave equation)

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial t} + \frac{\partial N}{\partial y} = 0$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{\tau_x}{\rho} - fN = 0$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} + \frac{\tau_y}{\rho} + fM = 0$$

$$M = D\bar{u}, N = D\bar{v}, D = h + \eta$$



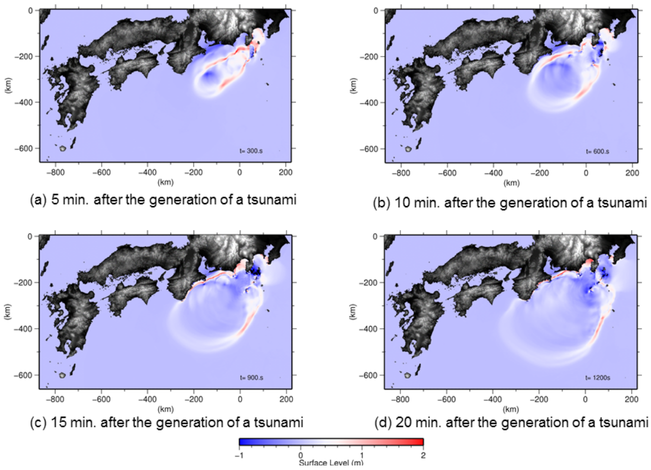
First wave of the 1944 Tokai-Tonankai interrelated earthquakes
(Aichi Prefecture Tokai and Tonankai Earthquakes Damage Prediction Research Report - 2002)

A tsunami simulation enables us to calculate the strength and scope of fluctuations at the bottom of the ocean with a fault model, and to measure their propagation by understanding the sea level change leading to the first tsunami wave. A non-linear long wave equation is used to simulate the propagation of a tsunami, whereas a simple linear long wave equation (which ignores non-linear elements) is used for seas deeper than 50 m (to put it simple).

The simulations you may often see on TV of a tsunami propagating on the Pacific Ocean (such as in anime) are often calculated with a linear long wave equation. It is a rather simple simulation, to the point you could do it at home with your computer. The only condition is for you to get information regarding submarine topography and the form of the first tsunami wave.

This is the result of a tsunami propagation simulation we did in our laboratory, for the 2002 Tokai-Tonankai interrelated earthquakes that were predicted and announced by the Aichi Prefecture. You can see in red the propagation of higher waves (= the tsunami), starting from the epicenters of the Tonankai Earthquake and of the Tokai Earthquake that reached the Suruga Bay to waters off the Kii Peninsula. This simulation enables us to understand that the first wave reached the tip of the Atsumi Peninsula in about 20 minutes.

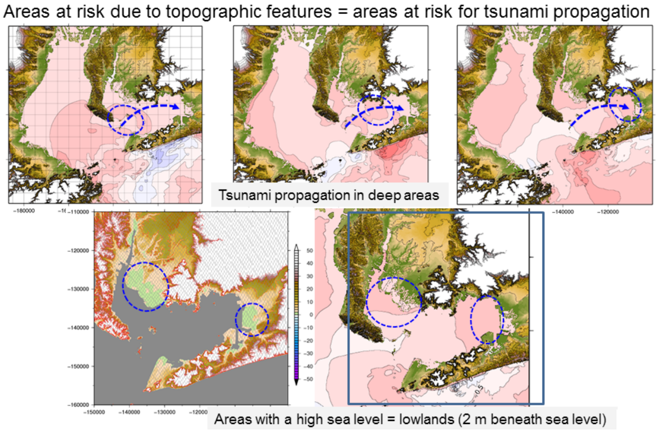
(Simulation Example)



(a) 5 min. after the generation of a tsunami
(b) 10 min. after the generation of a tsunami
(c) 15 min. after the generation of a tsunami
(d) 20 min. after the generation of a tsunami

Tsunami Propagation in the Mikawa Bay

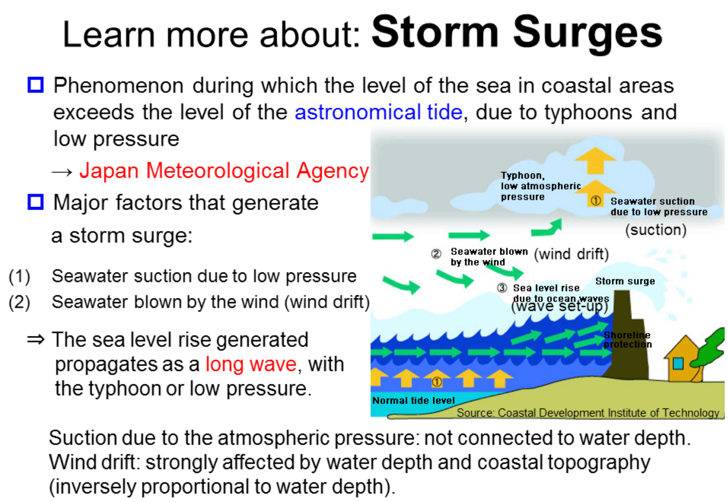
- Propagation of a tsunami (areas with a high sea level) coming from the ocean to the Mikawa Bay after having entered the Ise Bay
- Areas at risk due to topographic features = areas at risk for tsunami propagation



Here is the result of a tsunami propagation simulation for the 2002 Tokai-Tonankai interrelated earthquakes that were predicted and announced by the Aichi Prefecture.

The tsunami, which hit the coast by entering the mouth of Ise Bay, traveled through a very narrow passage between the Chita and the Atsumi peninsulas (Nakayama Suido sea route), and then hit the Mikawa Bay. This simulation enables us to understand that the tsunami traveled clockwise, first hitting Ishiki, then Katahara and Toyohashi. If we compare wave propagation to topographic features of the Mikawa Bay coast, we notice that the tsunami started to spread to areas below sea level in the vicinity of Ishiki, and then reached other lowlands surrounding the Toyohashi Port.

It is necessary to predict the consequences of such a disaster not only by taking into consideration the impact of a tsunami coming from the ocean on the coast (that is to say, what triggers a disaster), but also land factors (topographic features) of the areas it is supposed to hit. Some may think that the Mikawa Bay is less likely to be directly hit by a tsunami, because it is connected to the ocean by two narrow bay mouths (Ise and Mikawa). However, it is necessary to understand that some areas are potentially at risk for tsunamis (or other coast disasters such as storm surges).

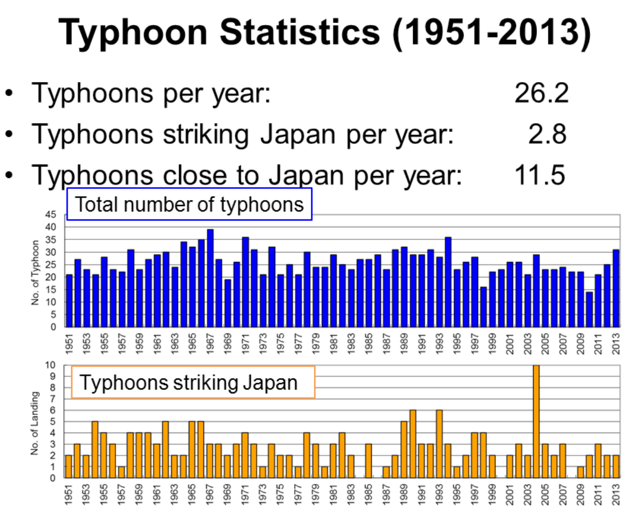


A storm surge is a phenomenon during which the water level increases higher than it usually does during the astronomical tide. The astronomical tide refers to global water level fluctuations due to celestial movements (centrifugal force, universal gravitation, etc.). Approximately 390 types of elements (tidal components) compose this tide, and the cycle of these elements range from 8 hours to 18.6 years. The sea level can be theoretically calculated, and the prediction results are posted online, such as on the Japan Meteorological Agency website. It is crucial to refer to water level fluctuations (tide difference) when designing coastal structures.

However, when a typhoon or very low atmospheric pressure are generated and approach the coast, 1) Seawater is sucked from the sea by low pressure (suction effect), 2) Seawater is blown downwind by a strong wind, and if there is an enclosed coastal sea in this same direction, the water level inevitably rises. This phenomenon can be compared to a long wave since it lasts for several hours, it occurs with a typhoon or low atmospheric pressure, in shallow seas. The water level rise due to the wind drift gets more dangerous in shallow waters, since it is inversely proportional to water depth.

$\Delta\eta=\tau\_s/\rho g h\, L$ $\Delta\eta$: water level rise, τ_s : sea shear stress due to sea wind, ρ : water density, g : gravitational speed, h : average water depth, L : bay size (distance for sea wind to have an

Here is a summary of the Japan Meteorological Agency information on past typhoons. There are approximately 26 typhoons a year. Among which 3 strike Japan. In Japan, typhoons that cause damage are usually referred to with numbers from 10 to 20. In 2009, 18 was the number of the typhoon that hit the Mikawa Bay and generated a storm surge. In November 2013, the typhoon that hit the Philippines, which caused considerable damage, was number 30.

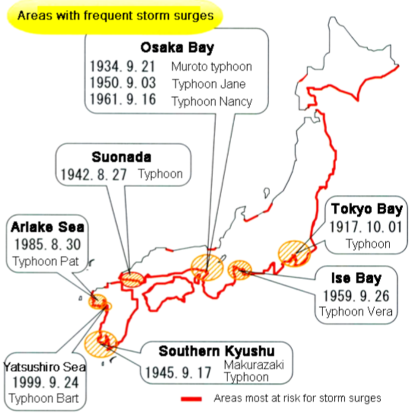


(Typhoons) The custom throughout the world is to give typhoons names. For instance, Typhoon No.18, 2009: Melor; No.30, 2013: Haiyan, No.15, 1959 (Ise Bay Typhoon): Vera.

A tropical cyclone that reaches a wind speed of 34 knots (17 m/s) or above is called a typhoon. (Japan Meteorological Agency)

Areas at Risk for Storm Surges

- Bays and inland seas with a mouth oriented in the direction of the typhoon.
- For the Pacific Coast, when the typhoon's path strikes the west side of a bay (dangerous semicircle).
- When the axis of a bay = the typhoon's path (strong wind blowing towards the inner part of the bay).
- Areas with relatively shallow sea.



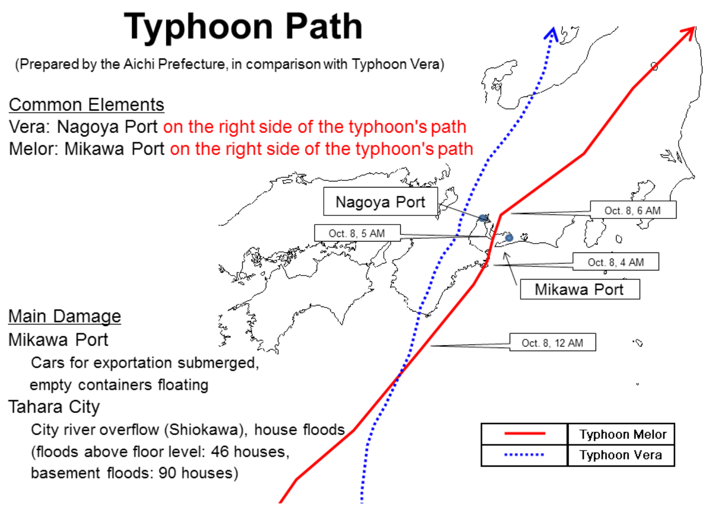
Here are the conditions for an area to be considered at risk for storm surges.

- When the mouth of a bay faces the typhoon's path.
- When the typhoon passes by the western side of a bay.
- When the axis of a bay coincides with the typhoon's path.
- When water is shallow.

When a typhoon comes from the south or southwest, all the Japanese bays on the Pacific Coast are at risk for a storm surge. This is especially the case with the three most important bays (Tokyo, Ise and Osaka), Ariake and Yatsushiro seas and the Seto Inland Sea.

A strong wind blows counterclockwise in the heart of a typhoon. When the path and wind direction of a typhoon are identical, the wind in its west side gets stronger, which is why it is called a dangerous semicircle. I have already said that shallow waters were particularly dangerous. Therefore, the route of a typhoon is a determining factor in storm surge generation.

Here is a comparison of the paths of Typhoon Vera (1959) and Typhoon Melor (2009). Since Vera hit the tip of the Kii Peninsula by the Shiono Cape to travel through the Kii Peninsula, the Ise Bay happened to be in the east side of the typhoon (forming a dangerous semicircle), which caused considerable damage to the coast, and especially around the Nagoya Port in the inner part of the bay.

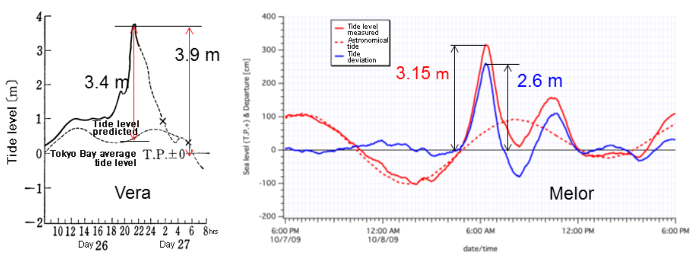


In 2009, Typhoon Melor traveled further east than Vera, and after having hit the east side of the Kii Peninsula, it hit the tip of the Atsumi and Chita peninsulas, and then traveled through the west side of the Mikawa Bay. At the time, the Ise Bay was on the west side of the typhoon, so there was no considerable damage in comparison to Vera. However, water level abnormally rose in the inner part of the Mikawa Bay, to the point cars got submerged and containers were floating in the sea. These two paths only differ a little, but such a difference is enough to generate a storm surge.

Major Storm Surge Damage in Japan (since Vera)

- Typhoon Vera (Sept. 26, 1959) (Mikawa Port, 3.30 m, 2.6 m)
  max. tide level T.P. 3.9 m, max. deviation 3.4 m (Nagoya)
- Typhoon Nancy (Osaka Bay, Sept. 16, 1961) 3.0 m, 2.5 m
- Typhoon Bart (Ariake Sea, Sept. 24, 1999) 4.2 m, 3.9 m
- Typhoon Melor (Mikawa Bay, Oct. 8, 2009) 3.15 m, 2.6 m

almost equal to Vera



Here I will present the particularities of the storm surges that hit the Mikawa Bay, such as the one caused by Typhoon Melor in 2009. Japan has faced a number of storm surges. However, Vera caused so considerable damage it made people think about preventive measures against other coastal disasters. The maximum level of water recorded for Vera was T.P. +3.9 m, with a 3.4 m deviation. In 2009, the maximum level of water recorded for Melor was T.P. 3.15 m, with a 2.6 m deviation (deviation in the Nagoya Port: approx. 1.0 m).