NEW BUILDING TECHNOLOGIES
Comment on
Displacement-Based Design

Didier Pettinga PhD P.Eng

OUTLINE

- Summarise a practicing engineer's perspective
  - Identifying with Force-Based Design (FBD) or Displacement-Based Design (DBD) – efficiency in application
- Personal experience in applying DBD
  - Reasons for turning to DBD
  - Opportunities to apply
  - Difficulties
- What has been effective and efficient to apply in practice
- Conclusions and current direction

PERSPECTIVE

- Force-Based Design – Practical Advantages
  - Apparently simple to understand given familiarity = comfort level
  - Quickly and efficiently adopted into computer models
    - Allows architectural complexities to be explicitly incorporated
  - Familiarity across the profession makes it easier to communicate
    - Particularly important for major projects with peer-review
- Force-Based Design – Practical Disadvantages
  - Don't really know what the amount of damage will be
  - Using Non-Linear Time History as verification we may get performance results that can't be related back to design assumptions – *surprises/setbacks/time consuming*

PERSPECTIVE

- Displacement-Based Design – Practical Advantages
  - Immediately achieve a better understanding of building performance
  - Forces the design engineer to target level/s of performance
    - Known damage potential under design level earthquakes
  - The NZ structural engineering community has exposure to DBD
    - Recent advances through presentations/publications
    - Parts of DBD terminology and target parameters are known & accepted here through recent design codes

PERSPECTIVE

- Displacement-Based Design – Practical Disadvantages
  - Conversely - the full methodology is not well understood in practice
    - By comparison to FBD it's an *unknown*
    - Unfamiliarity means practicing engineers find interpretation of key assumptions difficult
    - The hurdle of interpreting new material is more difficult than trying to iron-out the major bumps and inconsistencies of FBD
  - Adapting simple published examples to complex structures with less predictable behaviour is time consuming

DBD is a good example that

"to get to an answer, one must already know the answer"

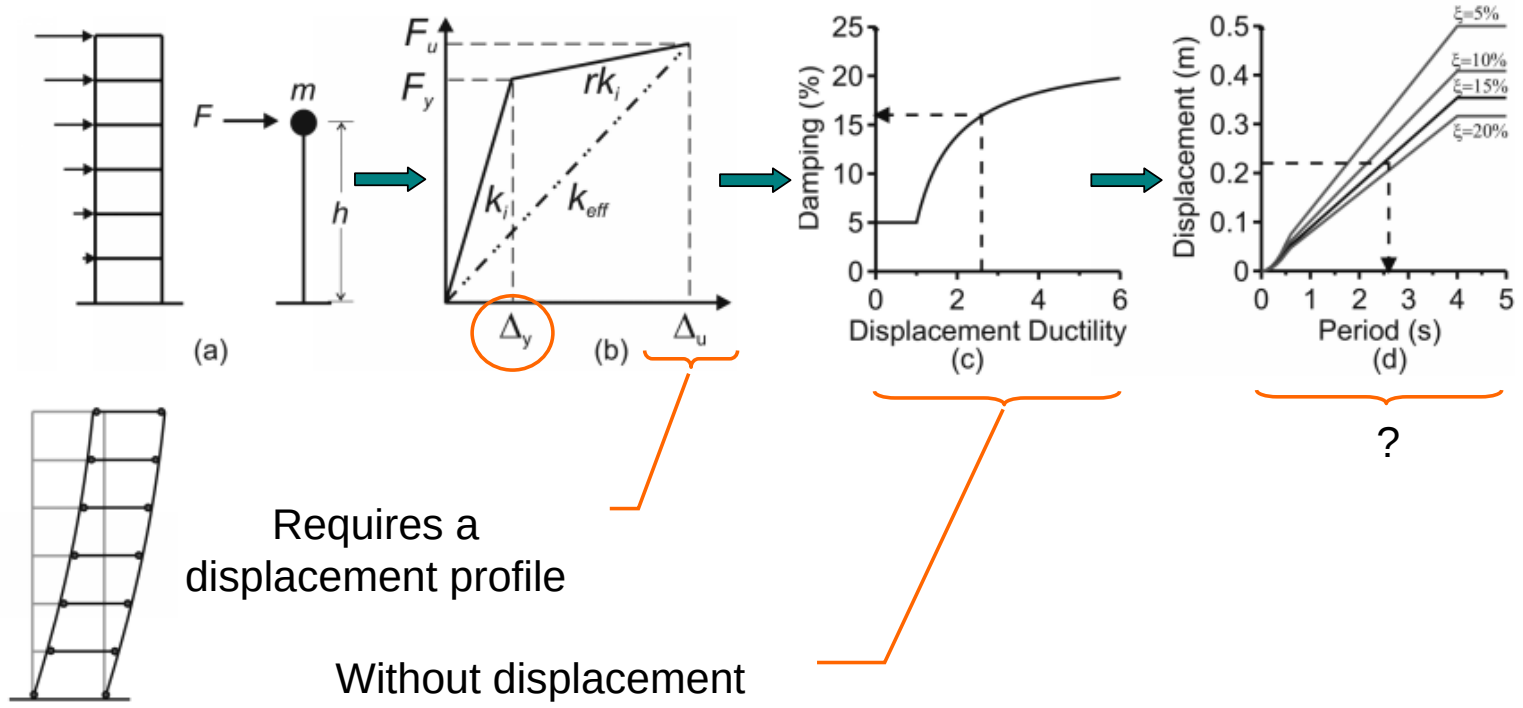
IN APPLICATION

- Displacement-Based Design: Key Requirements
  - Estimation of yield displacement
  - Estimation of a maximum displacement profile for the structure
  - Allowance for energy absorption
- Force-Based Design: Key Requirements
  - Assumption of cracked stiffness of the structural elements
  - Assumption of energy absorption

Without these DBD process can not progress

Where as critical FBD values are given by the relevant Codes

IN APPLICATION

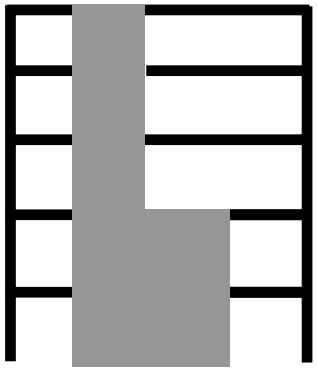


Requires a displacement profile

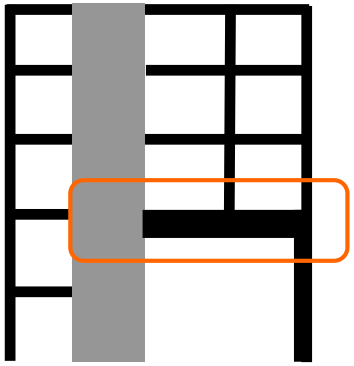
Without displacement profile can not calculate ductility

IN APPLICATION

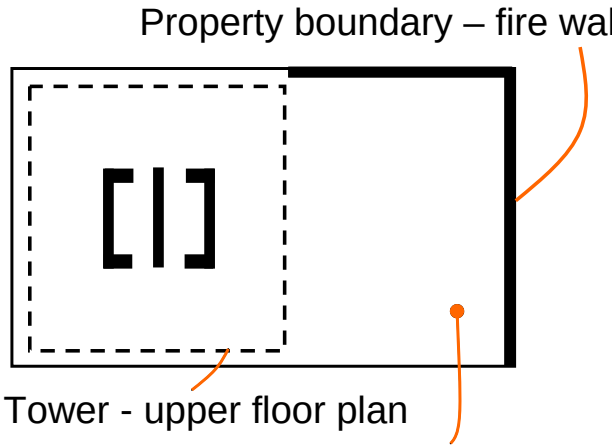
- Difficulties in applying DBD to complex structures
  - Current code environments still permit significant freedom in architectural & structural form
    - Results in buildings that almost always have irregularities:



Strength/stiffness changes



Gravity elements providing "unwanted" lateral resistance



IN APPLICATION

- Structural Irregularities such as these can significantly alter the key pieces of DBD
  - Unknown displacement profile at maximum response
  - Difficult to calculate Equivalent Viscous Damping

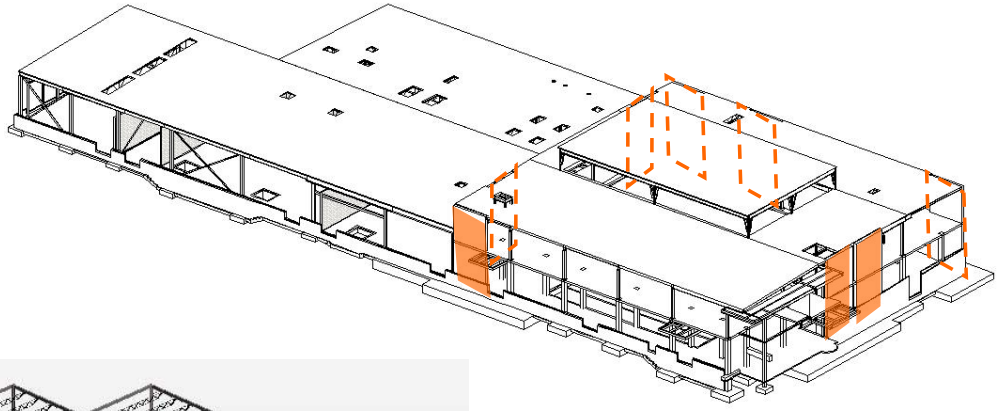
What is the displaced profile that will occur?

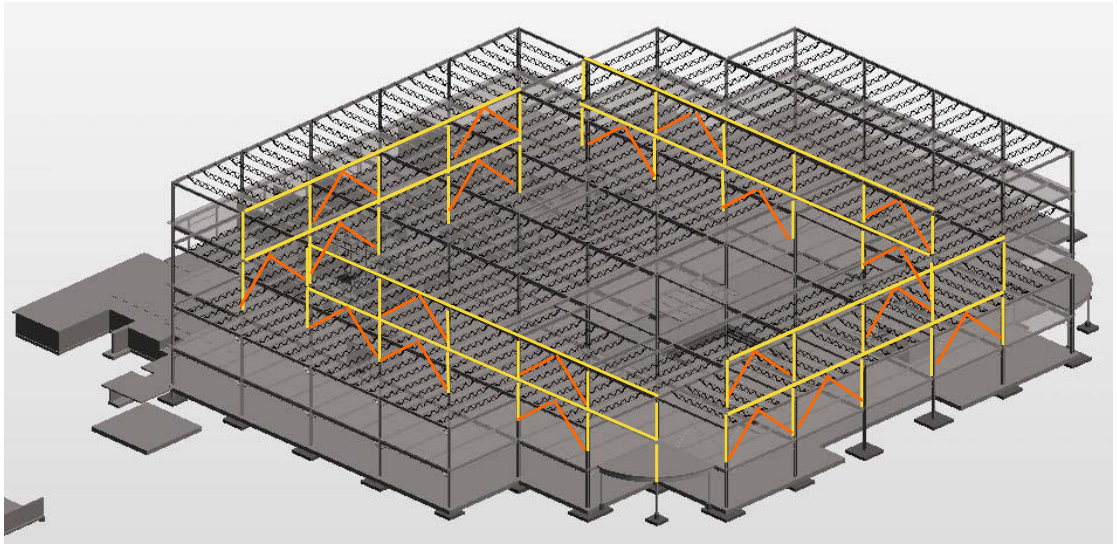
IN APPLICATION

- In these circumstances practice will naturally move back towards something familiar and efficient to getting the job done – Force-Based Design

IN APPLICATION

- However…
  - Found that simple and close-to-regular buildings do lend themselves to DBD





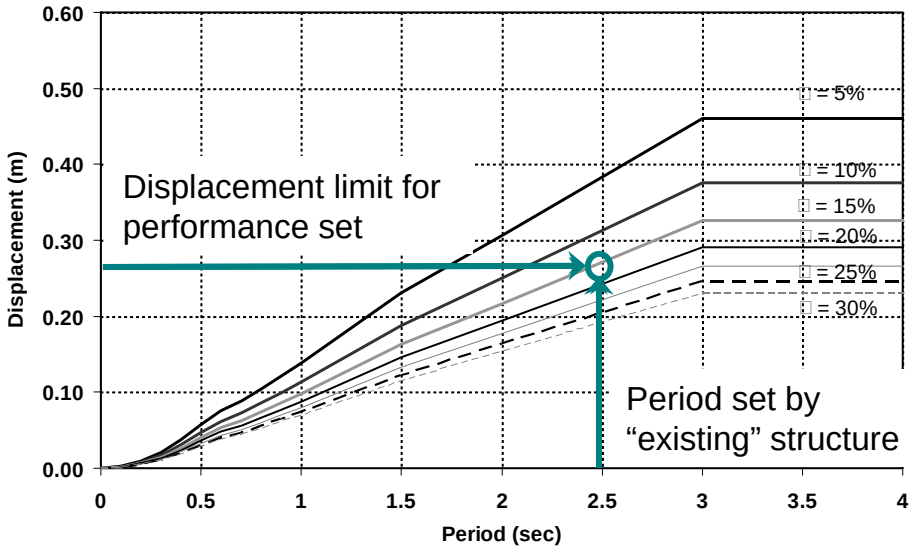
IN APPLICATION

- Designing to use devices with engineered response **and/or** with inherent re-centering behaviour are better designed using DBD
    - e.g. Viscous Dampers, Base Isolation or Self-Centering post-tensioned systems

DBD to incorporate high-performance systems is conceptually similar to existing displacement-based building assessment

- these buildings tend to have more regular form

- Fewer unknowns



IN APPLICATION

- Experience with Performance-Based Design (PBD) projects in California, Seattle and Vancouver B.C. suggests that key components of DBD can be adopted as additional design tools to Code FBD approaches
- These have enhanced the Code approaches and in-fact quicken the design/review process

EXPERIENCE OF APPLICATION

- American codes are quite prescriptive
  - PBD recommendations have been published to allow engineers to circum-navigate these restrictions
  - Aim to produce more efficient and arguably safer buildings
- Process is intensively peer-reviewed by a consulting firm, an academic and the City Chief Building Inspector/Reviewer
  - Immediate aim as the designer is to try and make the peer review process as efficient and painless as possible
  - Clearly FBD per Code + enhancements to the Code is the best option

EXPERIENCE OF APPLICATION

- Actual design is best driven by Code analysis with key checkpoints that apply DBD fundamentals
  - Basic building strength is set by Code-level analysis, but…
  - Estimate yield curvatures, rotations or displacements as a means to sizing walls/beams
  - Can update/revise cracked stiffness values according to displacement-based suggestions
  - Compare yield displacement to maximum code-allowed displacement limits
  - Compare this ductility back to the assumed code value

EXPERIENCE OF APPLICATION

- Found this approach to be very beneficial
  - High-Rise projects from 27 to 48 storeys
  - In all cases the basic building strength was determined from governing building code
  - However Non-Linear Time History analyses used for verification
  - Even if verified by NLTH - reviewers still lean heavily on the Code
    - So DBD + time history verification does not seem to be the best way forward for complex buildings
  - Found that initial displacement-based checks were closely borne-out by the final analysis results => no unexpected surprises

IN APPLICATION

EXPERIENCE IN APPLICATION

- Using elements of DBD to enhance the FBD code-approach helped peer-review in early and late stages of design
  - It provided upfront identification of potential problems or inconsistencies in the Code-based design
  - These could be adjusted/rectified before the high-level analysis phase started
  - Also could be used to confirm why certain results were found from the non-linear analysis results

DIRECTION FOR FUTURE APPLICATION

- DBD can be adopted into our design codes
- Appropriate as an alternative method
  - Apply to a restricted range of buildings
  - Satisfying rigorous regularity checks i.e. simple structural forms to apply published equations without needing time history analysis for verification
- For buildings that cannot meet such requirements then FBD is currently best option
  - Adopt specific displacement-based enhancements that ensure the designer identifies likely performance of the structure

IN SUMMARY

- DBD has reached a maturity that application in practice is possible
- But complexities of modern architecture and multi-use buildings can make adaptation of published methods difficult – time consuming
- For practicing engineers the major issue is time
- FBD and the ease of computer analysis still makes this the appealing option for most structures

IN SUMMARY

- Experience is proving that DBD is the better option for damped, isolated and self-centering building design
- DBD could be considered an acceptable alternative in code practice for a restricted range of buildings
- For more complex structures FBD can remain accepted with the addition of displacement driven checks to push designers to identify/confirm performance targets

IN SUMMARY

THANK YOU