TU1406
COST ACTION

WG2 and WG3 WORKSHOP

Bridge performance goals and quality control plans

Integrating multivariate techniques in bridge management systems for life-cycle prediction

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OVERVIEW

- BMS retains large quantities of data and metadata
  - Data – condition states through visual inspection
  - Metadata – crossing type, structural form, age (sometimes), etc.
- Possible to use multivariate data analysis techniques to analyse contents of bridge management systems (BMS)
  - "Big data analysis"
- Principal component analysis (PCA) is an effective data-reduction technique
  - Can define latent variables/underlying data structure
- Integration to existing BMS for improved asset base description

INTRODUCTION

- Aging, deteriorating bridge stock
  - Post-WW2 construction
  - Popular practice of “deferred maintenance”
- Increasing maintenance demands, less available funding
- Modern BMSs are a popular method to track and plan maintenance activities
  - Inventory (metadata)
  - Inspection (data)
  - Assessment
  - Maintenance
  - Financial

INTRODUCTION

- Large amounts of visual inspection data
  - Condition rating of individual elements
  - Overall based on worst condition primary structural element
- Simple to compare small number of bridges
  - Problem for larger data-sets
- "BIG DATA analysis"
  - Pattern extraction
- Data reduction techniques for latent variable structure
  - Principal component analysis
  - Latent variable – unobservable
    - Classic example: conflict prediction (turmoil, revolution, subversion)

MULTIVARIATE ANALYSIS OF BMS: Description of Dataset

- *Infraestruturas de Portugal*
  - Condition rating data for **3,036** bridges
  - 1,667 single span reinforced concrete
  - 713 single span masonry arch

Condition Rating	Description
0	No damage
1	Minor damage
2	Some damage
3	Significant damage
4	Critical damage
5	Ultimate damage

- Primary elements
  - Structural – deck, abutments, retaining/wing walls
  - Non-structural – surface, barriers, embankment

MULTIVARIATE ANALYSIS OF BMS: Assessment Methods

- Principal component analysis (PCA) is a multivariate analysis technique, the primary purpose of which is to reduce the dimensionality of a set of data

- Redefine the input variables as principal components (PC) – a linear combination of the original variables, but having a magnitude less than the original data set, but while preserving most of the information

- Highlighting the variables that demonstrate the most variance in the data set

MULTIVARIATE ANALYSIS OF BMS: Assessment Methods

- The first principal component Y_1 is defined as:

$$Y_1 = \boldsymbol{\alpha}'_1 \mathbf{x} = \alpha_{11}x_1 + \alpha_{12}x_2 + \ldots + \alpha_{1p}x_p = \sum_{j=1}^{p} \alpha_{1j}x_j$$

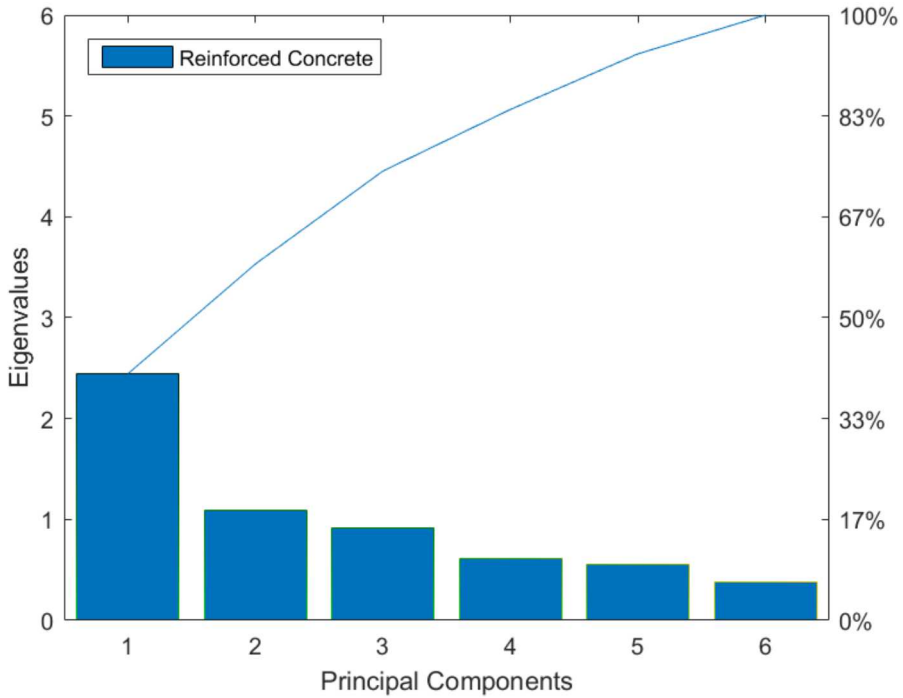
- The sum of the square of the coefficients α_i is equal to unity, and is a better indicator of the influence the coefficient has than the raw value:

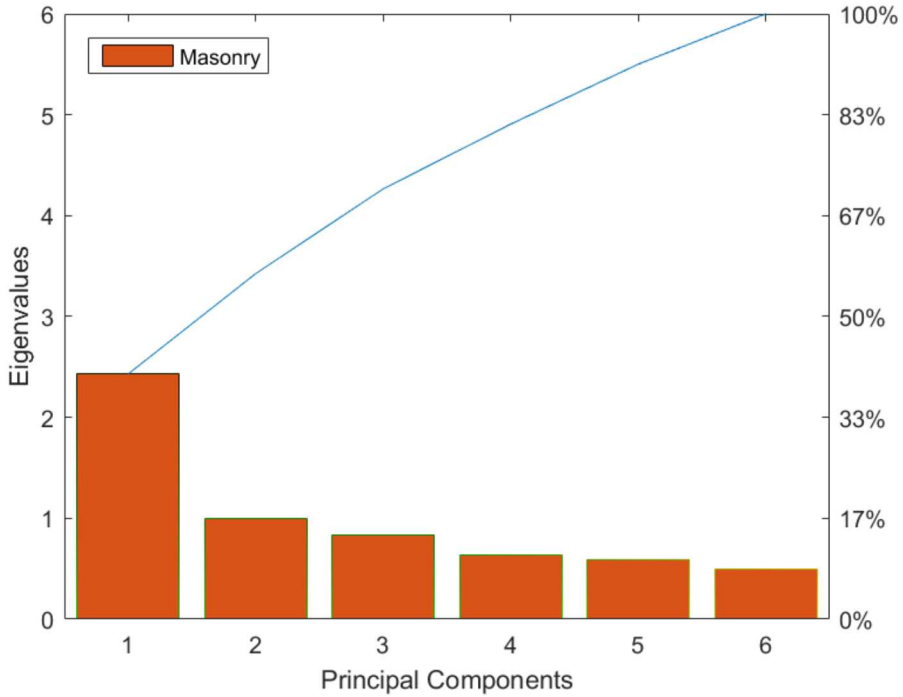
$$\sum_{i=1}^{p} \alpha_i^2 = \alpha'\alpha = 1$$

- The first principal component is the direction along which the data-set shows the largest variation
- The second PC is determined under the constraint of being orthogonal to the first PC and to have the largest variance

RESULTS: Number of PCs to Retain

- Determine the number of PCs to retain with scree plot of the eigenvalues
- Eliminate PCs with eigenvalues less than unity

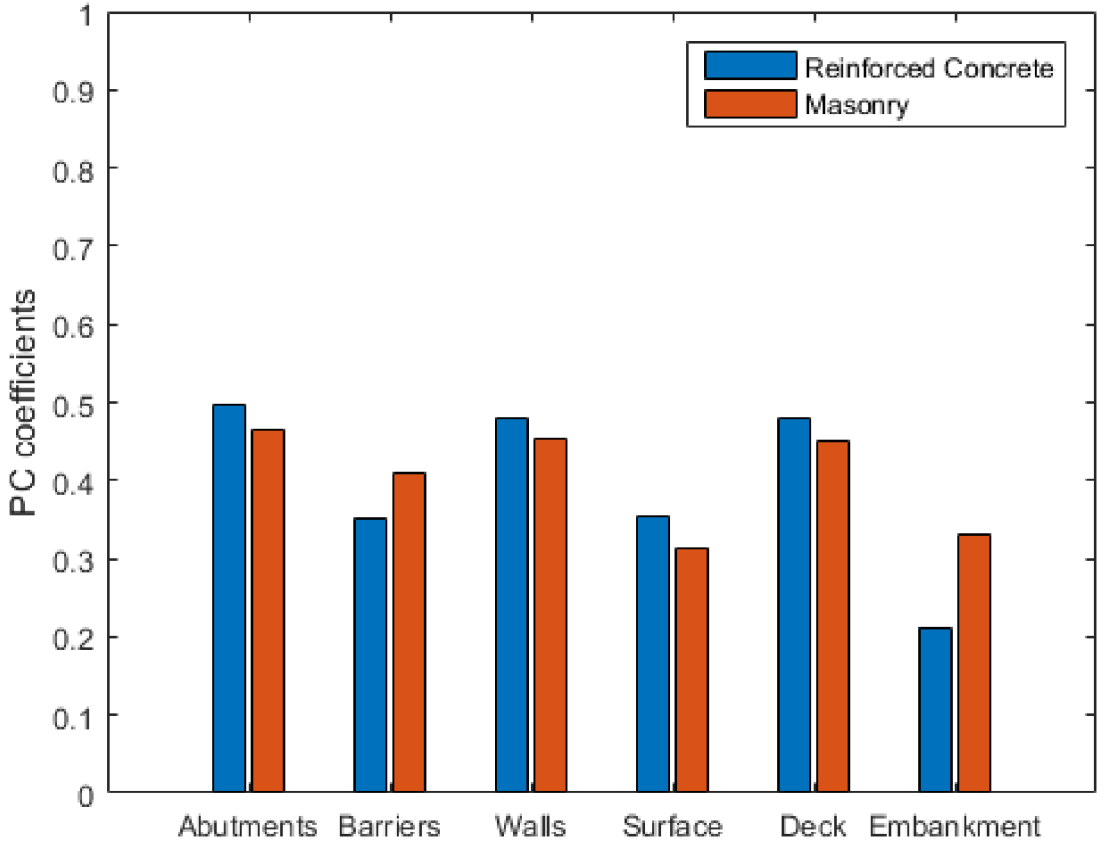




- Retaining: 1 PC (~41%), 2 PCs (~58%), 3 PCs (~72%)

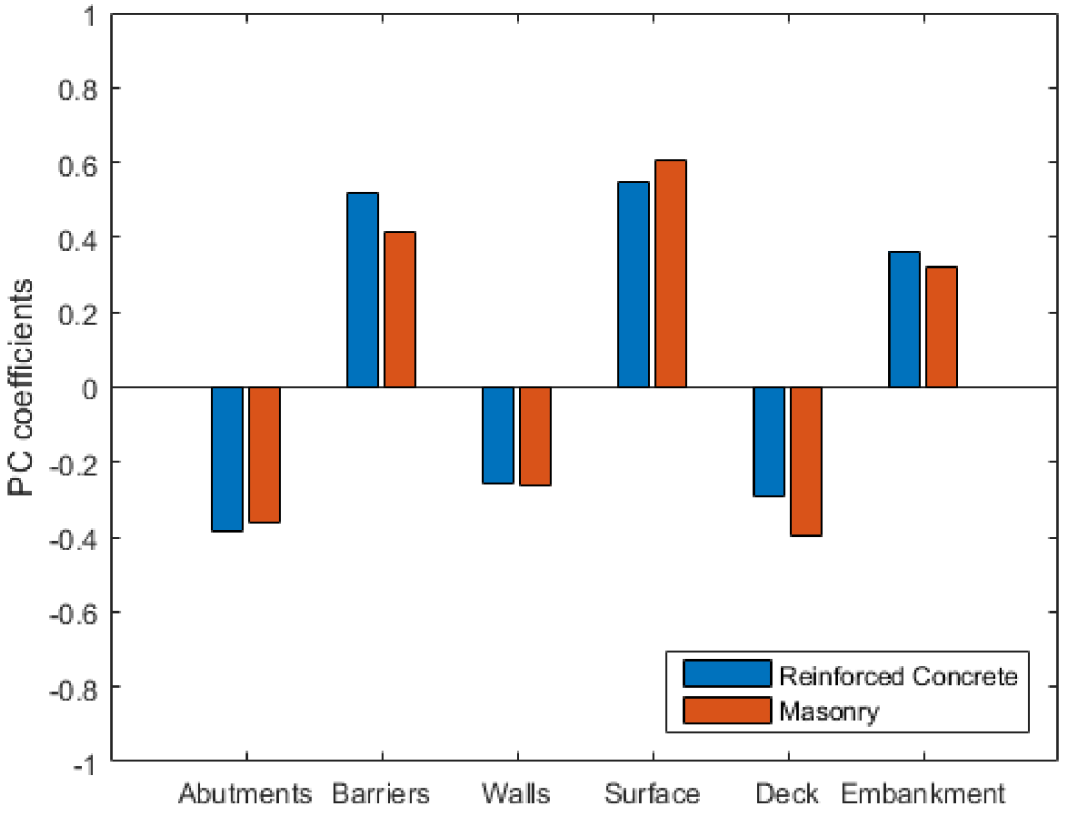
RESULTS: First Principal Component Coefficient, α_{1i}

- Indicate the relationship between original variables and new latent variables
- For this BMS, positive coefficients indicate unfavourable state, negati indicate favourable state
- 1st PC has all positive coefficients, indicating unfavourable state in eacl variable

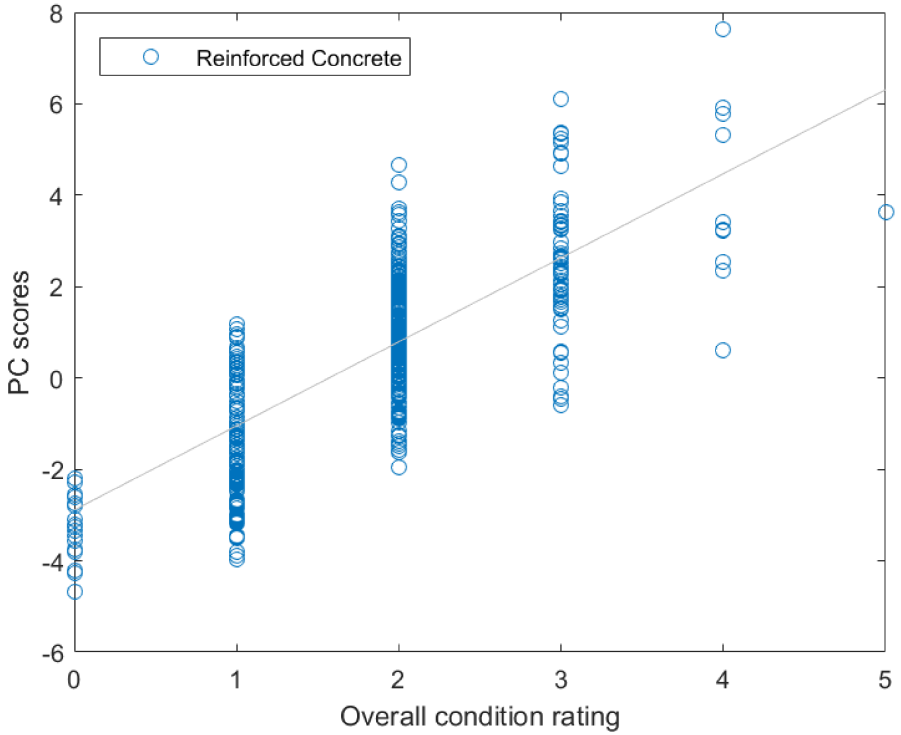


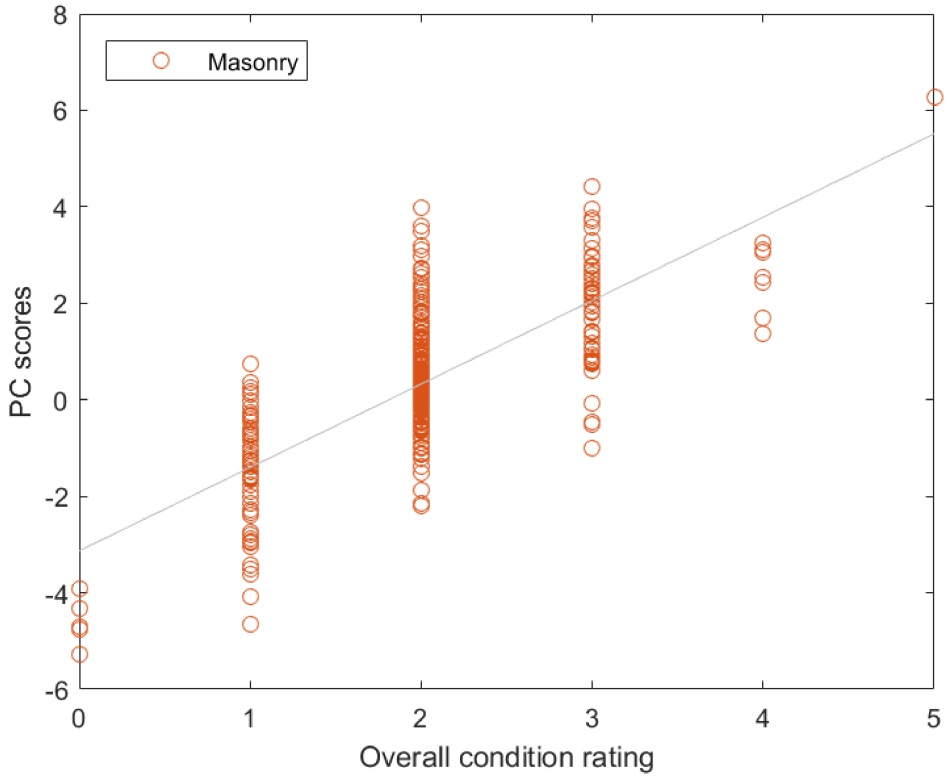
RESULTS: First Principal Component Coefficient, α_{2i}

- 2nd PC has mix of positive and negative coefficients, indicating disconnect between states for groups of variables
- Describes bridges where the structural and non-structural elements are in opposing states



RESULTS: First Principal Component Score, Y_1





BMS INTEGRATION: Weighted Condition Ratings

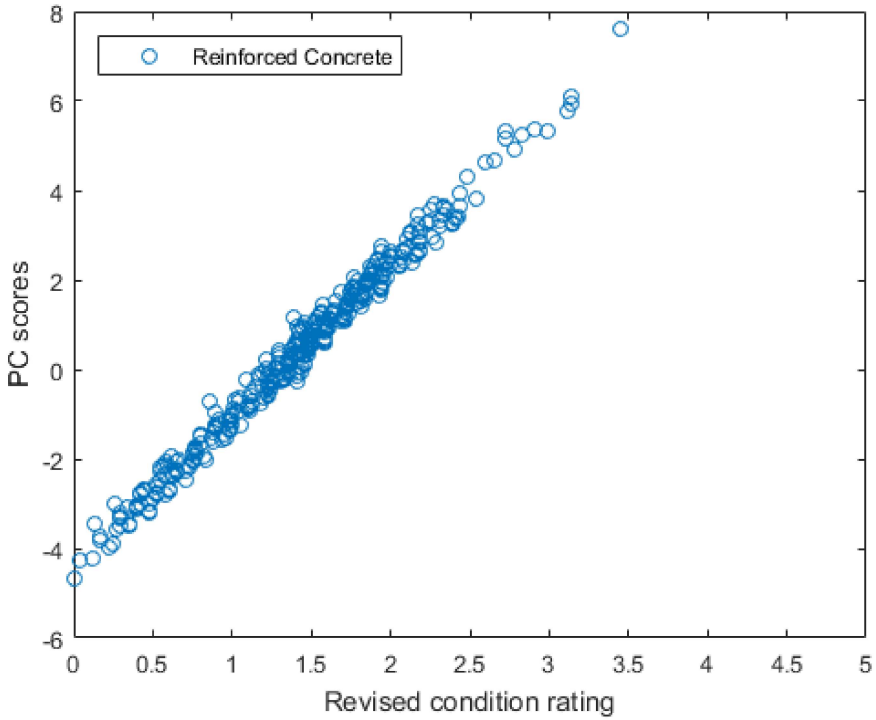
- Scope for improved overall condition rating
  - Weighted linear combination
- PC coefficients as first point guides

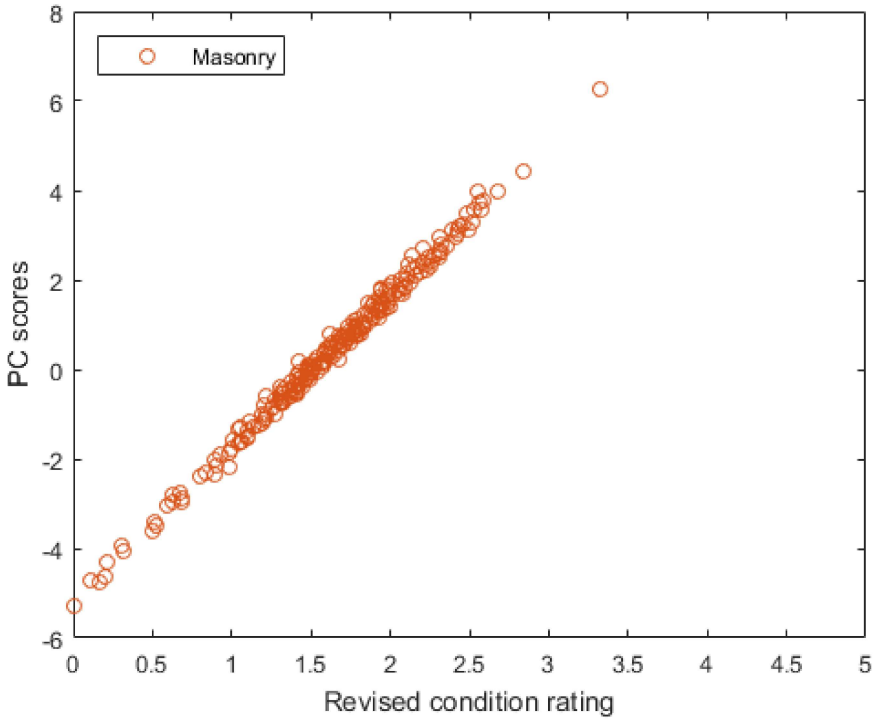
$$\zeta = \sum_{j=1}^{p} \lambda_j x_j, \quad \lambda_j = \alpha_{1,j}^2$$

- Where ζ is a linear combination of the new weighting factors λ_j and the original condition ratings x_j for the individual elements

Element	Reinforced concrete	Masonry
Abutments	0.2466	0.2166
Barriers	0.1238	0.1669
Walls	0.2290	0.2043
Surface	0.1255	0.0989
Deck	0.2300	0.2033
Embankment	0.0451	0.1099
Σ	1.0000	1.0000

BMS INTEGRATION: Weighted Condition Ratings





CONCLUSIONS

- PCA demonstrated commonality in latent structure between reinforced concrete and masonry arch bridges
  - Variances enough to caution against untargeted application
- Y1 is a good indicator of overall bridge condition state
  - Better descriptor than existing model
- Data extracted weighting factors good first point for BMS integration
  - Refinements based on current experience and knowledge base
- Further studies needed on larger, more diverse asset bases needed for reliable model
  - Region specific factors
  - Structure specific factors

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