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National Prize of Engineering
Project submission

Reinforcement of Historical Masonry with Long Internal Reinforcement Anchors

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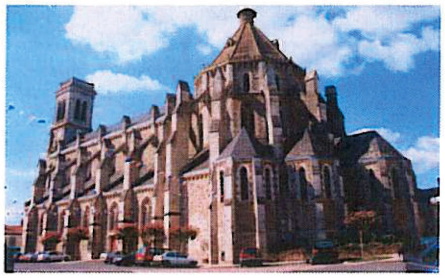
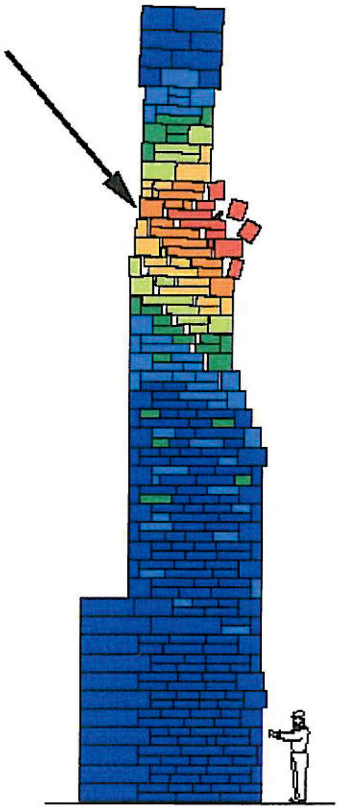
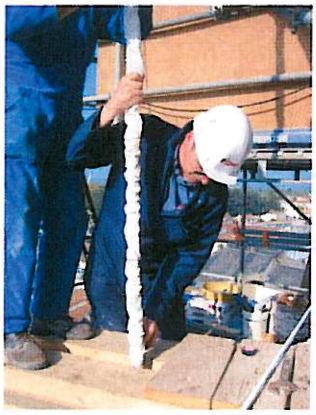
Qualitative Analysis using Discrete Element Computer Modelling for Seismic Loading and Oblique Forces







Application:
The Restoration of Aizenay Church

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07/02/2006

"The Birth of a Modern Technology for Safeguarding National Heritage"

Illustrated by the project Aizenay Church:
Putting in place an innovative solution for restoring buttresses in danger of collapse

INTRODUCTION

A presentation of an innovative new system under the following titles:

1) A first example in France for the use of long Cintec anchors. (installed within the 20 metre buttresses of a church).

2) A first ancient masonry project utilising the qualitative Discrete Element - LMGC 90 method.

3) A successful and unequalled demonstration of contained 'key hole' restoration justified both technically and economically.

4) A technique which in short opens a door for numerous hertiage applications, backed by sound engineering analysis and of special interest in areas of seismic activity.

1. Project Presentation

- ✓ Saint Benoit Church of Aizenay: classed as an Historical Monument, the structure has suffered considerably from cracking of buttresses due partly to foundation subsidence.
- ✓ Numerous seismic events of weak intensity hit the region during a seven year period 1997 to 2002 aggravating the structural damage.
- ✓ Following the fall of 20 kg of masonry block into the public car park below in 2001, the local authority undertook an emergency saftey study.
- ✓ After the inspection of the vertical and flying buttresses and a computer modelled analysis of the directional forces within. A program of consolidation work was defined in September 2002.
- ✓ The restoration work began in March 2003 and was completed in January 2005.

Project 'identity card'

Client:	Aizenay Town Council
Specialist contractors:	Hertiage Architect - P Jaunet - Briand Construction Finance - Cbt HUET Office of Structural Studies - CERT structure
Restoration Company (anchor installation)	BILLON S.A.

2. Analysis by the Engineers of CERT

2.1 Structural concerns of buttresses

- ✓ Movement and sliding of masonry on the corners of the buttresses, principally at the junction between the vertical and flying buttress (area of greatest concentration of force)
- ✓ Erosion of the mortar joins of hydraulic lime, crumbling of old mortar
- ✓ Appearance of cracking at the joins of the vertical and flying buttresses resulting from oblique forces especially in the area above the choir section pushing outwards and transfering through the flying buttresses.

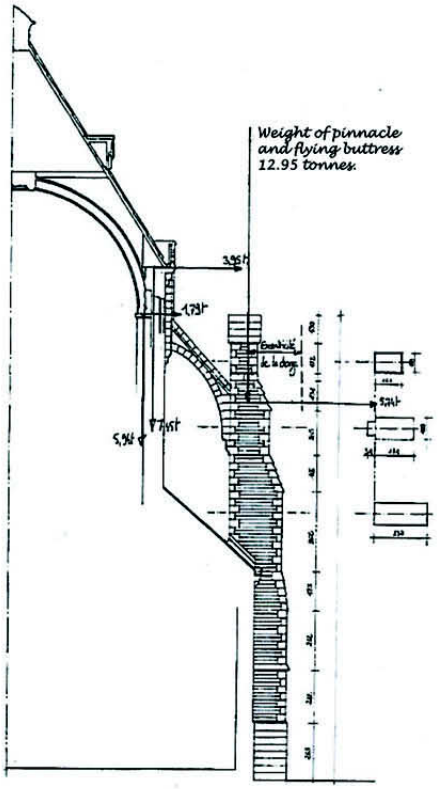
View of chior section

Ice damage and 'step' cracking

Degredation of limestone and old cement repairs

2.2 The Origins of the structural damage

- ✓ High forces exerted by the weight of the dome and the roof of the choir section. These are transmitted through the flying buttresses into the tops of the vertical buttresses.
- ✓ Concentration of oblique forces at the junction of the flying and vertical buttresses. These consist of dresses exterior stone and heterogeneous rubble infill and have experienced cracking to the right of the junction.
- ✓ The actual weight of the buttress pinnacles is insufficient to compensate for the oblique forces. A series of small seismic events have amplified the buttress damage.

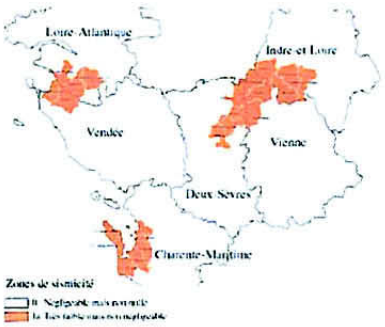


2.1 Stability and seismic activity

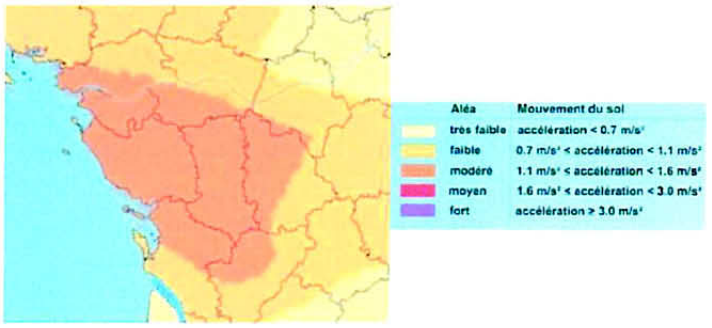
- ✓ The precarious stability of the buttresses calls into question the current balance of forces and their changeability (soil movements and vibration)

- ✓ Aizenay, situated in La Roche-sur-Yon and the seismic zone Ia (classification 14 march 1991) is at the heart of recent moderate earth movements which have clearly contributed to the structural damage incurred. (Tremors in La Roche-sur-Yon region in January 1998 and in Chantonnay in June 2001 and March 2002 - intensity 4 -5 on the MSK scale).

- ✓ The new map of seismic hazzard published December 2005 by the Ministry of the Environment and of Long Term Development, indicates the area of Vendée is classed as a "Zone of moderate seismic activity".



Current map of seismic activity



New map of seismic hazzrd on which appears the future zone classification

- ✓ In recognising the damage to the buttresses of in the choir area of the church and in the importance of opposing the oblique forces, the recent soil movements due to weak earth tremors must be taken into consideration.

- ✓ In this case an inert reinforcement in the most exposed zones (the buttresses) in an imperative (loss of 20kg of rubble stone falling in 2002).

2.4 Technical Solutions

Discounted Solution :

- ✓ It was possible to envisage the demolition and reconstruction of each buttress using reinforced concrete dressed with stone of identical appearance to the original.

- ✓ This technique imposes important project constraints: complete support to the dome of the choir area plus the shoring up of the walls during the dismantling of the existing buttress.

Weak also on economic grounds :

- ✓ Very high cost of work as well as longer planning problems when considering the urgency ;

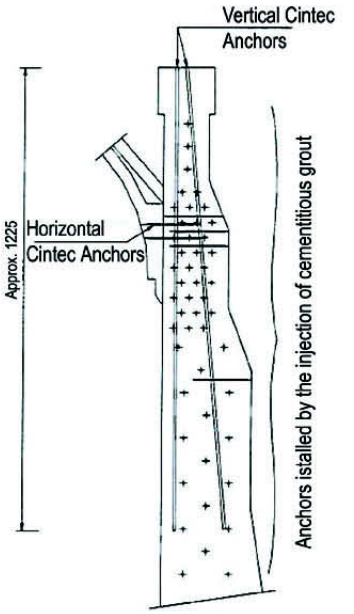
- ✓ A great deal of mess and disruption in the centre of the town ;

- ✓ Lack of heritage oreservation, new modern buttresses (concrete and facing stone).

Proposed Innovative Solution :
Reinforcement of buttresses using long internal reinforcement anchors

- ✓ Utilisation of the Cintec anchor system

Principle of buttress strengthening



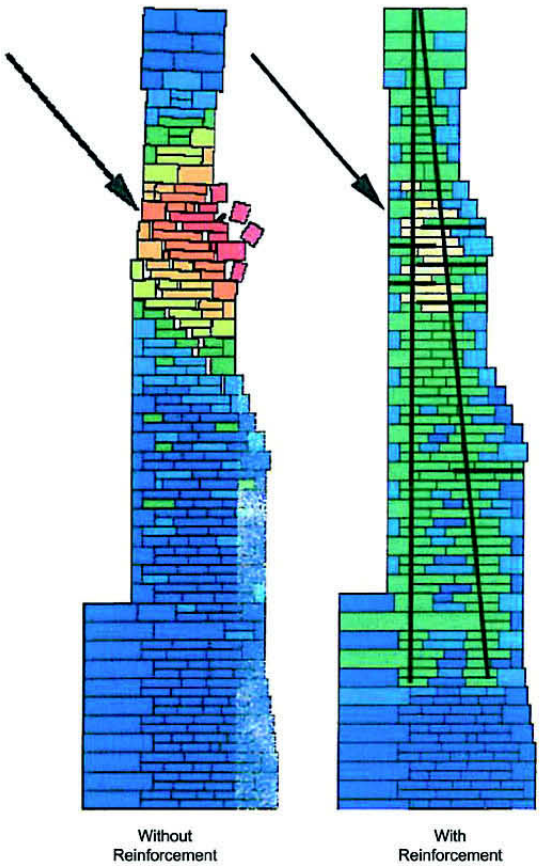
- ✓ This technology comprises a stainless steel bar within a sock of woven polyester into which a cementitious grout is injected under low pressure. The anchor is installed and inflated via a tube without the loss of grout into the neighbouring structure due to the polyester sleeve.

An original solution, reliable and economically sound :

- ✓ Rapid installation directly into the existing buttresses using scaffolding, without the need for propping up or buttress dismatling.
- ✓ Guaranteed anchor effectiveness along its entire length due to inflation beginning from the far end and grout containment within the sleeve ensuring full contact between the steel bar / grout / parent material.
- ✓ Respect to heritage and conservation due to anchor installation completely invisible within the buttress structure.
- ✓ Cost of intervention - three time less than proposed traditional methods.

3. VALIDATION OF INNOVATIVE SOLUTION

3.1 Qualitative analysis by Discrete Element to validate technical performance



The difficulty in modelling a masonry buttress rests in defining the behaviour between the masonry blocks.

The classic calculation method using Finite Element does not permit a non linear prediction of the masonry behaviour.

In order to take into account this behaviour, we have undertaken a new methodology of Discrete Element: The LMGC90 developed by the University of Montpellier II. The modelling by Discrete Element enabled a realistic description of the behaviour of old masonry since it takes into account laws of contact and rubbing between the different blocks (cracking profiles opposite the buttress joints)

In the case of the buttresses of Aizenay church, the computer modelling demonstrates the importance of the Cintec reinforcement within the buttresses by revealing the areas of force within the stucture both vertically and horizonally during seismic earth movements.

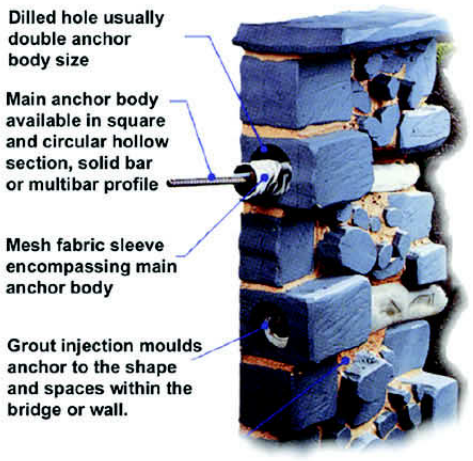
On a broader level, **CERT structure** has used this experience to develop a calculation code for the strengthening of old buildings under seismic loading.

4. ORIGINALITY OF ANCHOR SYSTEM

4.1 Cintec anchors 20m above the ground and of 12m in length

The capacity of the Aizenay church buttresses to take once more the oblique and horizontal loadings, has been augmented by the installation from the head of the pinnacles of Cintec Ø70mm/M25 anchors approx. 12m in length together with horizontally installed Cintec ties of circular hollow section.

The sleeve allows for the moulding of the anchor into the spaces along the length of the drill hole guaranteeing an adherence and cohesion with the neighbouring stonework of the buttress and without the loss of grout.



4.2 Inventiveness and performance

✓ The anchoring is a first in as much as no other French church has been reinforced in this manner. This type of structural failure is common in the buttresses of churches.

✓ The restoration is equally innovative in part for the choice of Cintec anchors (very little used in France), their length (greater than 12m) and their position (working at a height of 22m)

✓ The justification for the reinforcement was provided by the Discrete Element calculation approach and signifies an important advancement for its use in other ancient structures under seismic loading. CERT structure and the University of Montpellier are in the process of submitting a request for an A.N.R grant in order to continue this research and innovation work.

4.3 Photographic Report of the Anchoring

The drilling

The cores

The installation of a vertical anchor

Horizontal anchors ready for injection

Preparation of grout

Injected vertical anchor