A case study for base isolation design: Spark data centre facility – Auckland

2015 NZSEE
Conference

S. Javadian

Senior Structural Engineer, CPEng, MIPENZ

C.D. Treleaven

Technical Director, CPEng, MIPENZ, AECOM New Zealand Ltd

I.C. Franks

Structural Engineer, CPEng, MIPENZ, AECOM New Zealand Ltd

ABSTRACT: AECOM New Zealand Limited was engaged by Hawkins Construction to provide full engineering services for the design of a new data centre facility in Takanini, Auckland. The development brief required an importance level IV three-storey data storage building.

This paper outlines the decision making process for adopting a base isolation system in the development. It includes details of modelling and analysis of the structure and the benefits gained by pursuing this system.

An initial value engineering process revealed that a base isolated foundation system would provide the most economic design and the highest contents protection for the three-storey data storage building. The regular geometry of the building and grid spacing in both directions and poor ground conditions also added to the attraction of using a base isolation system.

The building and the base isolation system were modelled using SAP2000 software package and the final design was carried out based on the results from a non-linear time history analysis.

A system of identical lead rubber bearings was used, which initial investigations demonstrated a 65% reduction in the seismic base shear of the structure could be achieved as well as up to 90% reduction in floor accelerations at data hall level. The application of the base isolation system resulted in approximately 35% reduction in the construction cost of the structure's foundation.

1 INTRODUCTION

Spark (formerly Telecom) officially opened their new Data Centre in Takanini, Auckland on 31 October 2014. The Spark Data Centre is the first of its type to adopt modular systems and an elemental design approach to power delivery. It was designed and delivered within an ambitious timeframe to meet Spark's lease commitments. Successful delivery of the project required continuous close collaboration between key stakeholders Spark, Retail Holdings, Hawkins Construction and its consultant, AECOM. As a high reliability facility, the data centre brief specified compliance with TIA-942 Tier 3 requirements, or better. The building has highly specialised requirements for power systems and cooling the data server spaces, which means each floor is substantially dedicated to plant and equipment. From a structural perspective, this translates to high floor loadings, high importance level (IL4) for seismic design, coupled with a low seismic acceleration threshold at the data hall floor level to meet TIA requirements.

Paper Number O-65

Seismic base isolation of the whole building was considered early in the design process as an efficient solution to TIA floor acceleration requirements and minimizing seismic base shear at foundation level. The facility owner was open to the concept, conditional on the fixed project outturn cost not being exceeded.

This paper explores the specific attributes of this development that resulted in a net capital cost saving for a base isolated building compared to conventional construction.

2 BUILDING DESCRIPTION

The three storey data storage building has a simple rectangular footprint 53m by 37m. The columns are located on a regular grid of approximately 6m by 7m with a 2.5m corridor in the middle. The roof is lightweight with upper floors being a metal tray on a braced steel frame system with concrete topping. These floors support data hall and mechanical plant spaces. The ground floor, which supports the power system for the data centre, is Double Tee slabs supported on concrete beams and isolator caps under each column. Isolators are supported at ground level by a network of concrete tie beams which interconnect the pile foundation system.

Typically, data hall floors are designed for high live loading (12kPa in this instance) to allow for heavy and sensitive data storage racks and their maintenance requirements. Figure 1 shows a 3D visualisation of the data storage building. The isolator caps and the gap through the isolation plane can be seen at the base of the building.

Figure 1. A visualisation of the new Spark Data Centre Facility.

3 GROUND CONDITIONS

The site geotechnical investigation identified 7-10m of very soft peat or mud overlying Waitemata Group siltstones and sandstones across the site. A piled foundation for the building was chosen on this basis. The most challenging aspect of the pile system design was selecting a system allowing efficient transfer of the building seismic base shear from ground level to the underlying sandstone.

A site specific seismic hazard analysis (SSSHA) was undertaken to confirm the site classification and the appropriate seismic design spectra for Serviceability and Ultimate Limit State events. The SSSHA concluded that subsoil class C was suitable for this site. It also identified that the natural period of the soil at the site is about 0.5 seconds, which was a crucial piece of information to have when evaluating the suitability of the site for a base isolated building.

4 VALUE ENGINEERING

The value proposition for including base isolation in the structural design of the facility was initially to reinforce the emphasis on high reliability of the data centre in service. Data centre design requires huge investment in maintaining power to the data racks and avoiding single points of failure to ensure that Spark’s commitments to its customers are met. Base isolation of the building substantially reduces the risk of data centre operation being compromised by the effects of a design level seismic event.

This is normally implemented at an incremental increase in the capital cost of the facility. Whilst the primary whole of life benefit of having an isolation system is to provide reliable protection against a low probability – high consequence event, it usually comes with extra costs associated with providing an extra floor (compared to slab on grade construction), the cost of the isolator hardware, and added complexity in the design of services that pass through the isolation plane. Typically, base isolation is an easier sell in locations with higher seismic risk than Auckland.

Quite early in the design process some of the site and project specific parameters made base isolation attractive as a potentially cheaper alternative than a conventionally designed structure.

- The lowest floor had to be suspended due to the soil conditions, which meant that the substructure cost increment was reduced to pile caps and tie beams.
- Isolation substantially reduced the seismic base shear demand on the foundation system. This enabled a hybrid piling design to be employed, with screw piles provided under most of the interior column positions to resist vertical loads, and large diameter bored piles socketed into sandstone to resist lateral loads. Pile caps were interconnected at ground level with tie beams to ensure transfer of lateral load from each isolator to the bored piles.
- The isolation system resulted in a correspondingly low floor acceleration in the data hall located at level 2, and other suspended levels. This eliminated the need for seismic isolation of individual racks (which would have otherwise been a requirement for TIA-942 level 3 compliance), and significantly reduced the bracing requirements for building services (Fig. 2) designed for “parts and portions” loading.

Figure 2. Interior view of plant room. Floor accelerations significantly reduced the need for lateral bracing of building services.

A cost analysis of options showed that the base isolated option, including the suspended ground floor, LRB isolators, tie beams, pile caps and hybrid pile solution, was approximately 35% cheaper than the lowest cost non isolated option including suspended ground floor and integrated foundation. Improved reliability of the structural performance under extreme conditions was considered an added benefit.

5 DESIGN PROCESS

Incorporating the isolation system properties into the structural design was necessarily iterative and required staged input at key times from the isolator supplier. The design approach at all times required consideration of the building, the isolators and soil-foundation behaving as an inter-related system.

5.1 Base isolation system

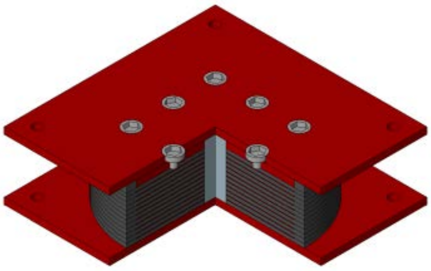

Figure 3. 3D cut-away view of the lead rubber bearing base isolator.

Initial appraisal of isolation system performance led to a target building period of about 1.7 seconds. This gave a meaningful reduction in spectral response, comfortably away from the site period, and within the capability of several isolation technology systems.

After considering different isolation systems and input from isolator manufacturers, cylindrical lead rubber bearings, supplied by Robinson Seismic Ltd (RSL), were adopted for this building. Sixty isolator positions were incorporated into the layout, using a single isolator type. A schematic 3D view of the cylindrical lead rubber bearing is illustrated in Figure 3.

Structural modelling commenced using preliminary isolator properties, which were progressively updated once load and deflection data were obtained from the model.

5.2 Analysis

The building was modelled using SAP2000 general purpose finite element analysis software. SAP2000 features include a built-in non-linear link element. The appropriate properties of the specific isolation system can be defined using this built-in element and assigned to isolation locations.

Using initial isolator properties, equivalent static and response spectrum analyses were run to validate the initial assumptions for isolated natural period and maximum isolator deformations. Several analyses were required to conform to the requirements of EN15129, one using isolator stiffness 20% greater than proposed to provide an upper bound value for base shear, and another using isolator stiffness 20% lower than assumed to provide an upper bound of isolator displacement.

Site conditions dictated that rigid support conditions below the isolation plane could not be assumed. The screw piles were modelled as vertical supports allowed to slide horizontally. The bored piles were modelled using line elements and lateral restraint was provided by non-linear springs defined using the P-y curves derived from geotechnical analysis. Only screw test piles were installed. Generation of the initial P-y curves using load deflection testing of screw piles was included in the pile testing programme to help calibrate P-y performance in the modelling for bored piles with observed test results. These were extrapolated to account for the differences in stiffness and end fixity between bored piles and screw piles.

Introduction of soil-structure interaction slightly increased the natural period of the structural system which provided a modest reduction in the overall system lateral response. The building response above ground remained as a rigid block with the first three modes of vibration responsible for about 90% of the participating mass. Figure 4 shows the extruded view of the SAP2000 model with the isolation plane visible, along with the superstructure and bored piles.

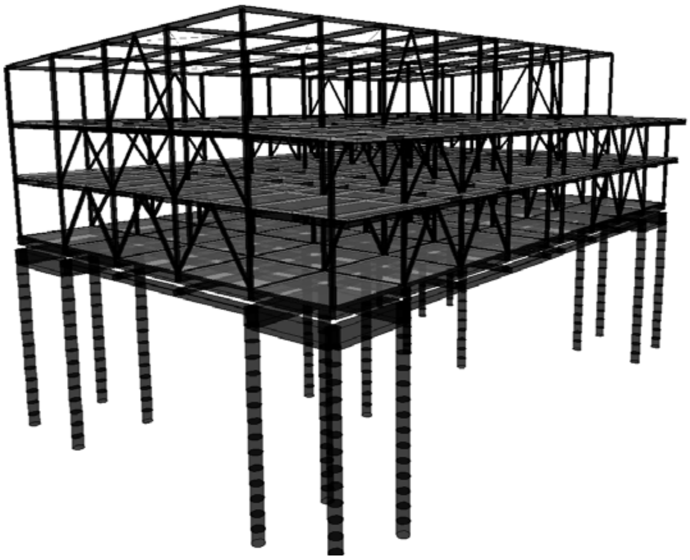

Figure 4. Extruded perspective of SAP2000 model.

Once the isolator properties were finalised, the modelling phase moved to non-linear time history analysis (NLTHA). This required identifying and applying seven suitable earthquake records. The output from the NLTHA:

- Provided final design actions for the structure and foundation system which were consistent with the outcomes predicted in value engineering.
- Identified floor accelerations for TIA-942 compliance and design of services restraints.
- Confirmed displacement range required (between 80-110mm for Ultimate Limit State events) for design of services connections through the isolation plane.

6 COMPLETED STRUCTURE

Spark officially opened the new Data Centre on 31 October 2014. It was designed and delivered within an ambitious timeframe to meet Spark's lease commitments. The construction programme was assisted by a design philosophy of predominantly prefabrication components and simple, repetitive connections, as well as the reduced number of concrete bored piles due to adopting a base isolation system. Figure 5 shows an outside view of the completed Data Centre Facility.

Figure 5. Completed Data Centre Facility.

7 CONCLUSIONS

The Spark Data Centre gained several key benefits from incorporating a seismic base isolation system into the design; high reliability, reduced service bracing and piling requirements, and significant cost savings. The superior dynamic performance of the superstructure, which is designed to survive an Importance Level IV seismic event undamaged, is entirely consistent with Spark’s requirements and market expectations for a high reliability facility.

The site ground conditions were influential in opting for a base isolated structure. The very soft soils over sandstone dictated that a suspended slab and piling would be required for a heavy three storey building. This eliminated the choice of a non-suspended ground floor and shallow foundation, which is a traditional cost differentiator counting against isolated buildings. The reduction in seismic base shear attributed to the isolation system enabled significant cost savings to be gained in the construction of the foundation designed for lower lateral loading.

Reduced floor accelerations at every level of the superstructure resulted in low bracing demands for suspended services above the isolation plane, even by Auckland standards. This more than offset the additional detailing requirements for services which passed through the isolation plane.

The completed project therefore represents a proven example of superior performance of a high reliability facility at lower capital cost through provision of seismic base isolation.