2007 年 6 月 11 日

昂坪纜車

車廂墜下事故

專家委員會報告

(中文譯本)

註：

由於本報告主要是由海外專家滙編，
所以報告內容的最終解釋是以英文版本為主。

目錄 頁

前言

2007 年 6 月 11 日晚上 8 時許，昂坪纜車的 21 號車廂被發現倒在 2B 號塔旁的地上。車廂損毀嚴重，其後證實車廂是從離地約 50 米的高處墜下。圖 1 為 21 號車廂的殘骸照片。

圖 1－ 21 號車廂的殘骸

2. 當時車廂內並無乘客，墜落地點為 2B 號塔旁的草叢。事故並無導致人命傷亡及財產損失。

圖 2－ 2B 號塔範圍環境

3. 事故發生時，纜車正進行年度檢驗（下稱「年檢」），當時天氣情況穩定。年檢由 Skyrail-ITM (HK) Ltd. (下稱「Skyrail」) 委派的一名獨立檢測員進行。Skyrail 亦調配了維修保養人員參與年檢。年檢乃按架空纜車（操作及保養）規例第 211A 章第 20 條要求的法定程序。

4. 政府委任專家委員會，對事故進行詳細調查，旨為確定事故成因，重新評估纜車設計、操作、保養及管理，確認補救措施以防止同類事故再度發生，並對纜車重新開放予公眾使用的先決條件提出建議。專家委員會由三名成員組成，秘書及技術支援由機電工程署提供。

主席 : Gabor Oplatka 教授
副主席 : Josef Nejez 教授
委員 : 陳帆太平紳士工程師

5. 報告交代專家委員會對 2007 年 6 月 11 日昂坪纜車車廂墜下事故的調查結果。報告分為以下三部分：

第一部分 － 事故成因及防止將來再發生同類事故的建議
第二部分 － 對纜車設計、操作、保養及管理的評估
第三部分 － 纜車重新開放予公眾使用的先決條件

背景資料

6. 昂坪纜車於 2006 年 9 月起開放予公眾使用。纜車採用雙纜式設計，全程 5.7 公里，每個方向的每小時最高載客量為 3,500 人。於最高載荷時，昂坪纜車可動用 109 個車廂，每個車廂最多可載 17 人。纜車的最高行駛速度為每秒 7 米，但自 2006 年 9 月開放予公眾使用以來，運行速度一直保持在每秒 5 米 [1]，讓纜車克服與安全無關的前期操作問題，滿足公眾對纜車可靠性的期望。

7. 纜車系統採用循環式路線，令車廂可同時雙向運載乘客。兩個纜車總站分別位於東涌及昂坪，兩個轉向站分別位於機場島及彌勒山，另有八個編號為 1、2A、2B、3、4、5、6 及 7 的中途塔，其中 1 號塔最接近東涌纜車總站。纜車線道分為兩段，每段有其獨立的驅動裝置、制動系統及獨立的纜索系統。

第一段－ 此段較短，由東涌纜車總站至機場島轉向站，全程 0.6 公里。

第二段－ 此段較長，由機場島轉向站至昂坪纜車總站，全程 5.1 公里。

[1] 機電工程署於 2006 年 8 月 15 日致地鐵公司信函 ref.(47) in EM GL/03/10 SF11(A1)

8. 機場島轉向站配備驅動裝置及制動系統，並為纜車提供第一個轉向點。另一個轉向站位於彌勒山，為纜車抵達昂坪總站前提供第二個轉向點。

9. 昂坪纜車採用雙纜式設計。纜索分為導軌纜及牽引纜兩種，如圖 3 所示，兩種纜索的用途有基本上的分別：

> 導軌纜是固定纜索，直徑為 70 毫米，作用是承載車廂重量及提供暢順導向，令車廂朝運行方向移動。
>
> 牽引纜是移動纜索，位於導軌纜之下，直徑為 42 毫米，作用是通過可拆除式夾扣，牽引車廂沿導軌纜運行。纜車抵達總站時，可拆除式夾扣會自動打開，使車廂脫離牽引纜，並以低速在輸送系統中前進，以便乘客在總站登車或下車。

圖 3－ 雙纜式纜車及車廂

10. 圖 4 及圖 5 分別為昂坪纜車的平面圖及線道圖

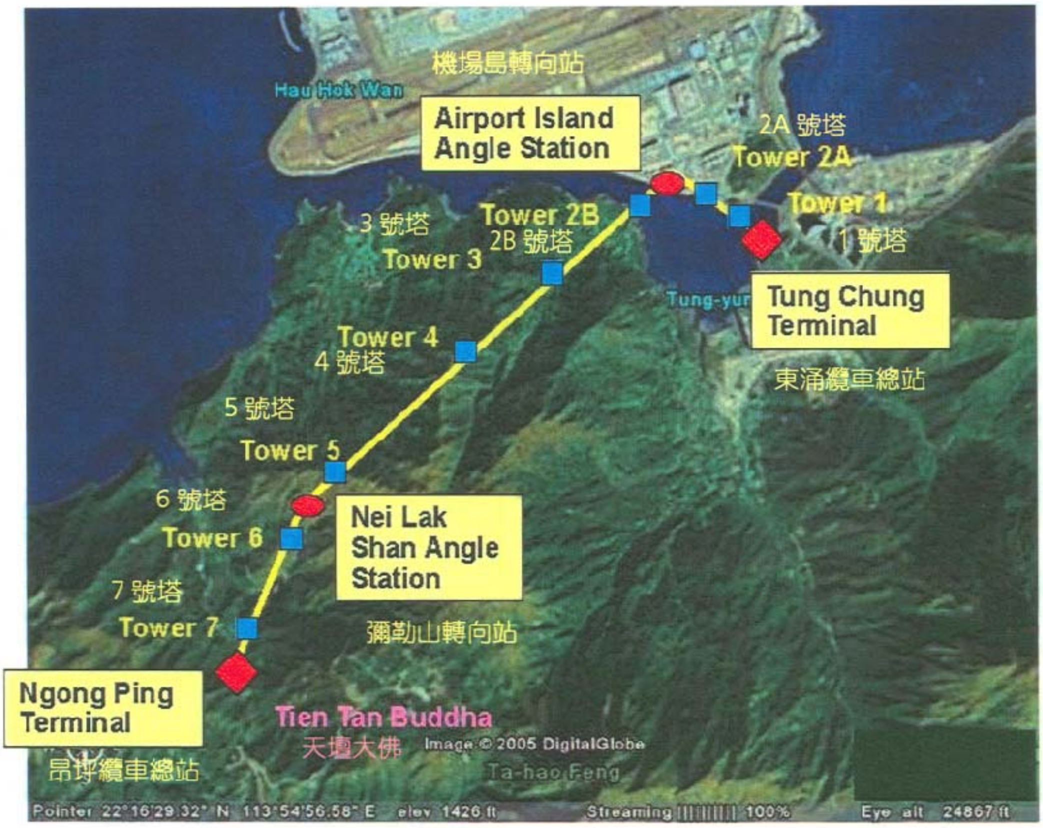


圖 4 — 昂坪纜車平面圖

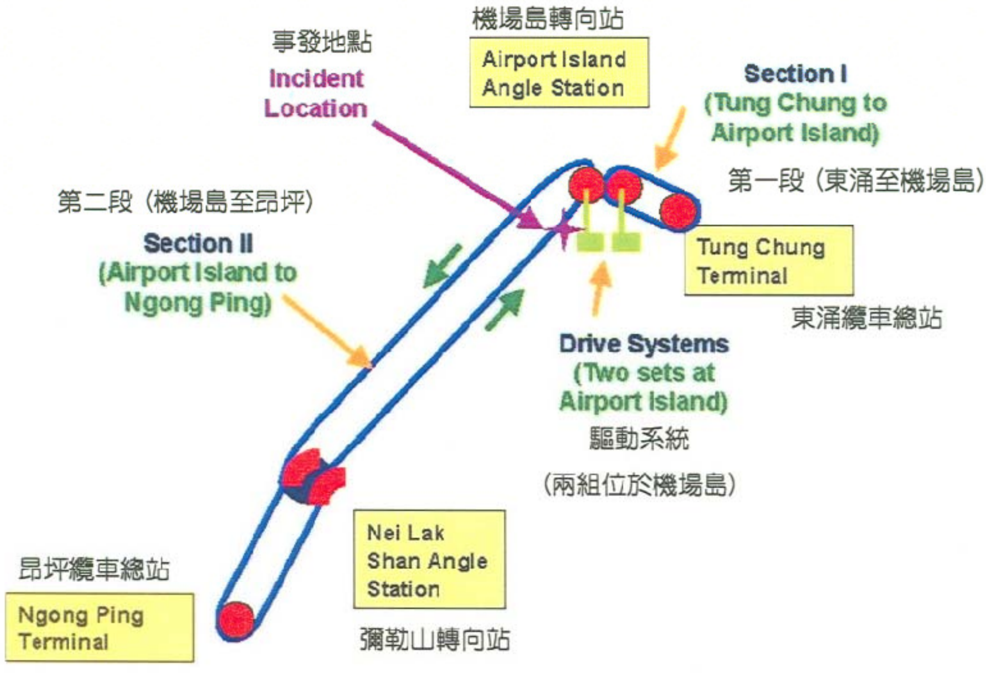


圖 5 — 昂坪纜車線道圖

第一部分

事故成因

及

防止將來再發生同類事故

的建議

第一部分 - 事故成因及防止將來再發生同類事故的建議

調查方法

11. 專家委員會採用的調查方法概述如下：

11.1 分析所有數據，尤其是纜車監控及數據收集系統 (SCADA) 所錄得的制動曲線及所有相關資料的時間記錄；

11.2 研究及檢討生產商的纜車操作及保養手冊，以確立有關制動測試的建議及與事故有關的措施；

11.3 就事發經過的細節及其前後的事態發展，會見 Skyrail 的有關員工、獨立檢測員，以及纜車生產商及擁有人的代表。

11.4 檢查、查核及分析與事故相關的纜車組件，包括已損毀的 21 號車廂及其吊架、導軌纜及牽引纜，以及 2B 號塔上已損壞的滑輪。

11.5 進行實地測量，並以理論及數據分析車廂與牽引纜的動態特性。

11.6 安排政府化驗所及香港生產力促進局進行科學鑑證。

觀察及調查發現

12. 事故發生後對纜車組件進行目視檢查的發現：

12.1 除 21 號車廂嚴重損毀外，2B 號塔上共有 13 個滑輪損壞（圖 6），而 2B 號塔若干結構部分亦有刮痕。

12.2 導軌纜狀況良好，惟發現有一條長 173 米的淺刮痕（圖 7）。

12.3 牽引纜表面有數處出現輕微損壞，位置在出軌車廂的夾扣位及其周圍（圖 8）。

圖 6－ 2B 號塔上共有 13 個滑輪損壞

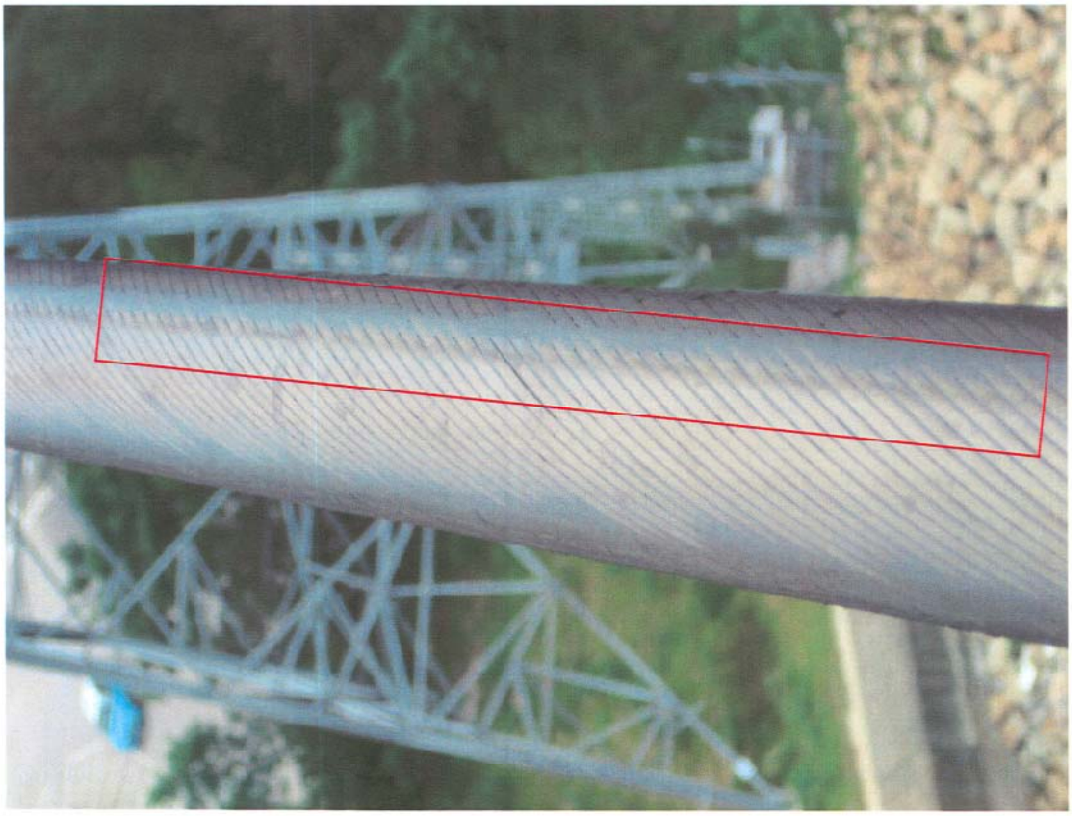


圖 7－ 導軌纜有 173 米長的刮痕，此為其中一段

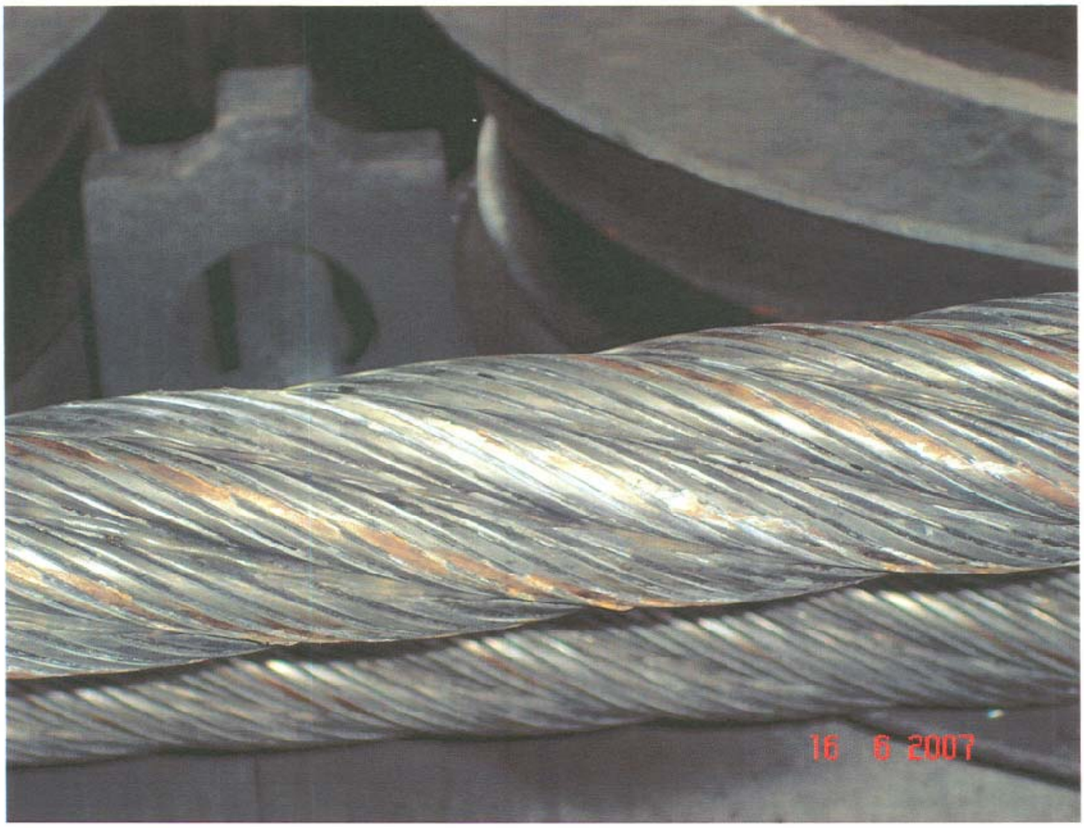


圖 8— 牽引纜表面有輕微損壞

13.　　專家委員會對纜車系統及組件進行一系列的檢驗及測試，並特別著眼於 2007 年 6 月 11 日進行年檢的制動測試。

14.　　纜車驅動系統的制動器分為兩組 [2]。在正常操作時，兩組制動器受自動調節控制，從而令纜車在受控情況下減速，然後安全停下。制動系統也可由人手控制進行測試，模擬調節控制失靈情況，但在模擬測試中必須避免過度減速。纜車生產商訂明，第一段的減速率必須維持於每秒 2 米/秒以內，而第二段則維持於每秒 1 米/秒以內 [3]。

15.　　2007 年 6 月 11 日晚上進行的空載車廂制動測試是年檢的一部分，由獨立檢測員訂定測試程序，Skyrail 的維修保養人員負責人手操作纜車系統。其中一個測試項目就是模擬其中一組制動器調節控制失靈。據知在測試期間於 19 時 39 分，兩組制動器均由維修保養人員操作，結果在第二段造成纜車以每秒減速 1.6 米/秒的過急減速。

16.　　過急減速令車廂前後擺動，及導致牽引纜產生垂直波動。從導軌纜上的刮痕推斷，相信在距離 2B 號塔約 173 米處，21 號車廂受本身的擺動及纜索過度擺動影響，被向上拋起，最後導致脫軌（圖 9）。

[2]　操作及保養手冊第 3.3.2 節「制動器」，C 部分 1.2.

[3]　操作及保養手冊第 5.1 節「制動測試」，測試及調試報告，參考 A1，第 C 部分

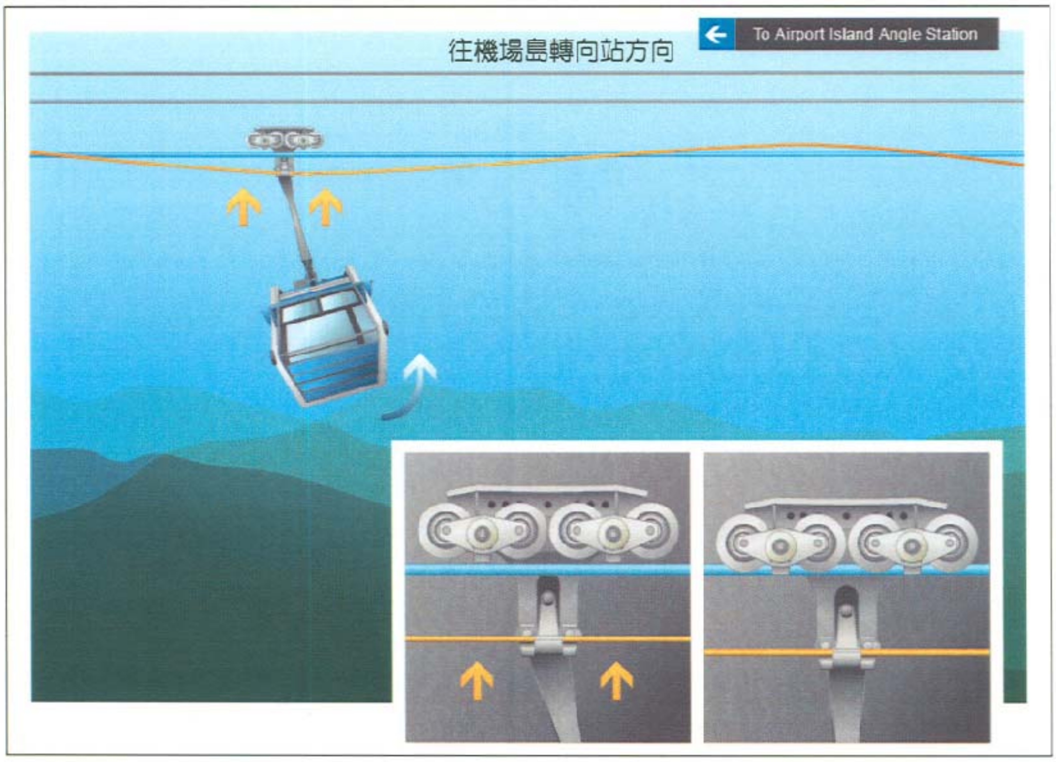


圖 9 — 21 號車廂因擺動及牽引纜過度擺動而被向上拋起（右邊小圖顯示吊架的正常位置）。

17.　　在 19 時 39 分發生脫軌情況後，車廂只倚靠車站導向滑輪的迴接軸繼續掛靠在導軌纜上，情形如圖 10 所示。脫軌情況無人發現，當纜車重新啟動時，已脫軌的 21 號車廂的吊架被牽引纜拉向 2B 號塔。該吊架在導軌纜上向前滑動，引致導軌纜上出現刮痕，鎖定螺絲母磨損，導軌纜的潤滑劑沾到滑輪上。過程由以下檢查結果證實：

17.1　導軌纜上由脫軌處起至 2B 號塔，出現長 173 米的淺刮痕；

17.2　車站導向滑輪鎖定螺母下方發現磨損痕跡（圖 11），及

17.3　車站導向滑輪內側發現油脂層，證實與導軌纜所用的潤滑劑相同（圖 12）。有關科學鑑證由政府化驗所進行，參見附件一。

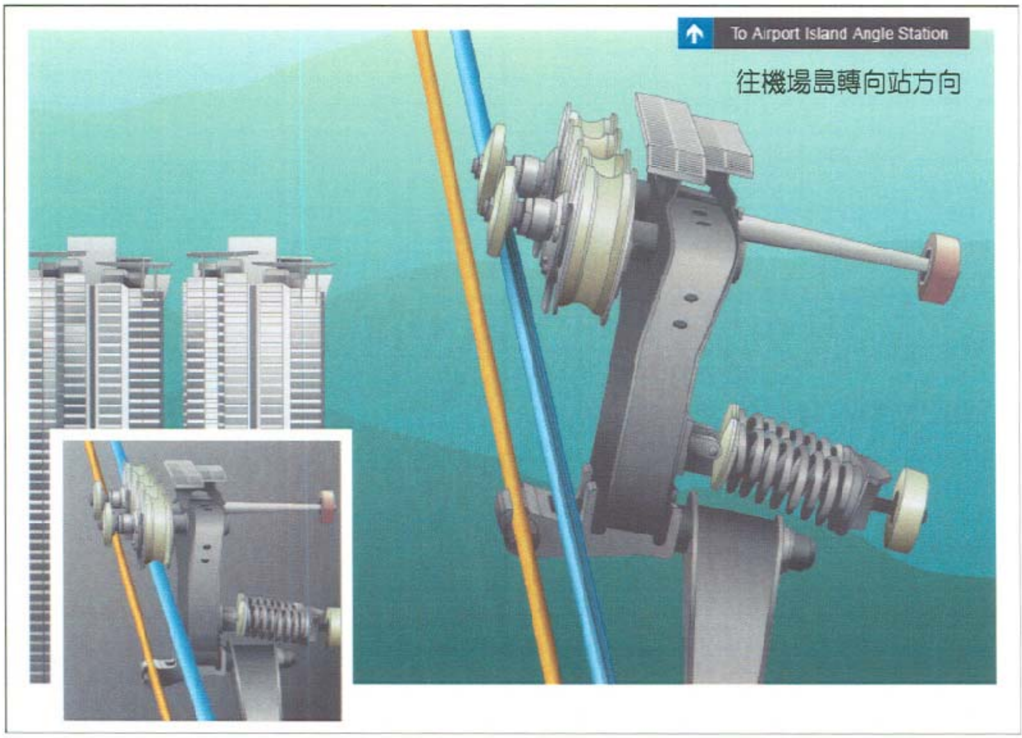


圖 10－　21 號車廂脫軌，並以吊架上的車站導向滑輪連接軸掛靠在導軌纜上

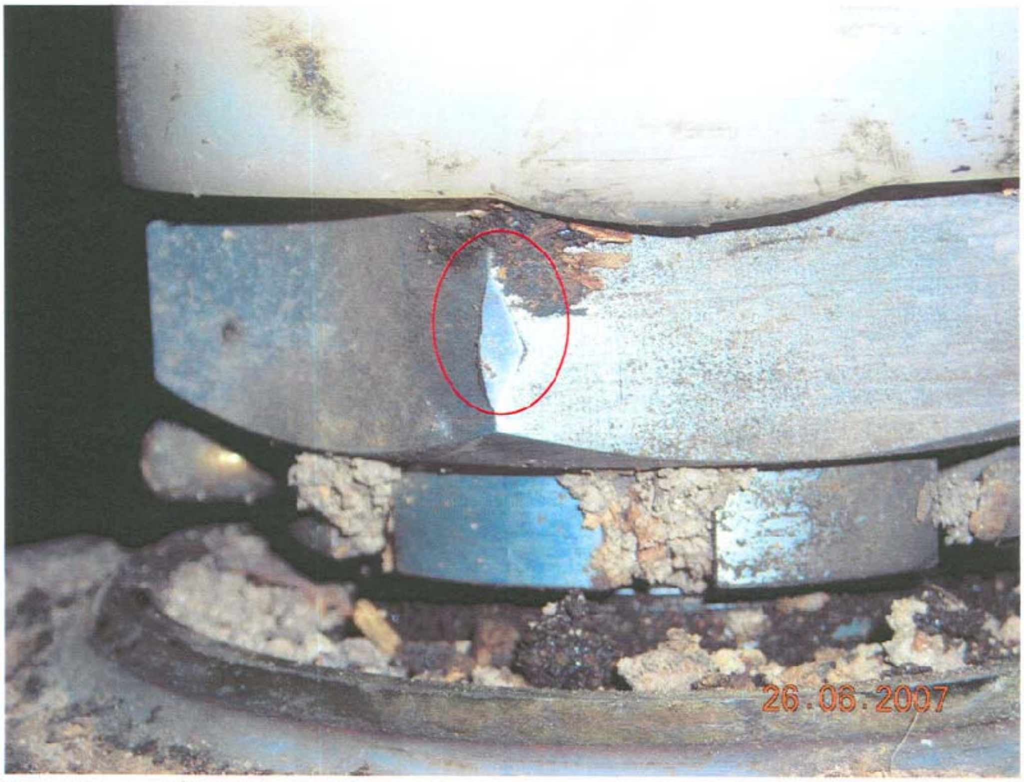


圖 11－　車站導向滑輪的鎖定螺母下方發現磨損痕跡

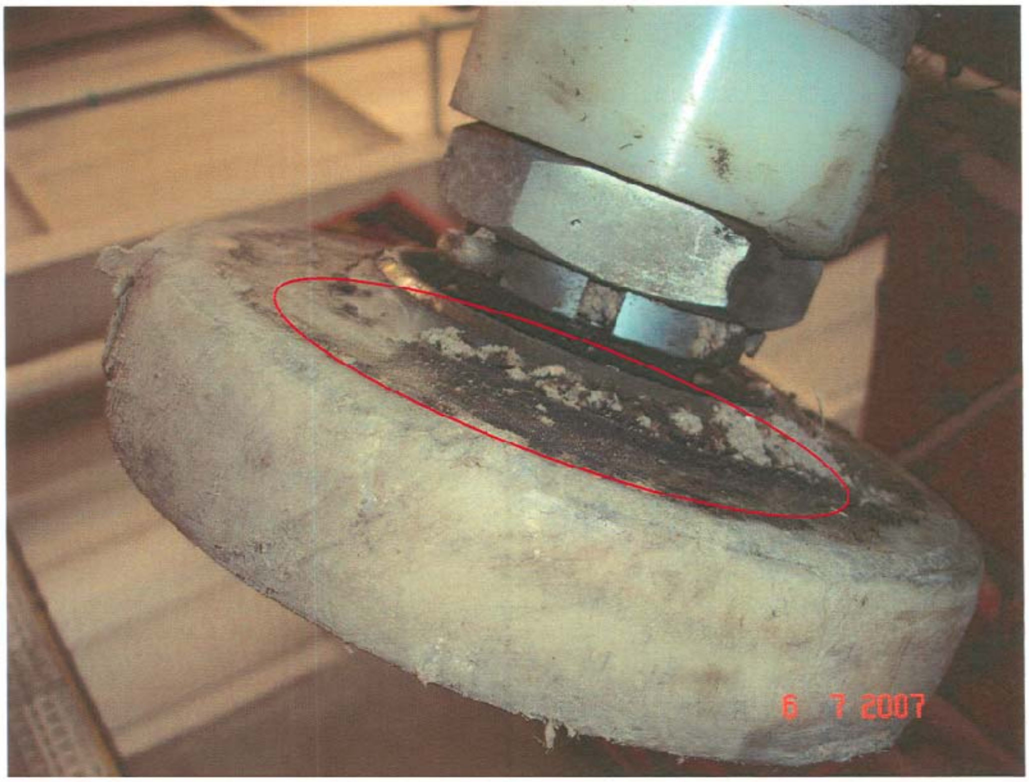


圖 12— 車站導向滑輪內側發現沾上油脂層

18. 由於脫軌的 21 號車廂移離正確位置（圖 13），吊架到達 2B 號塔時，可拆除式夾扣與一組裝置於塔頂的滑輪組碰撞（圖 14 及 15），導致滑輪和牽引纜夾扣損毀。圖 16 顯示撞擊後受損的滑輪。大約在第 11 個滑輪的位置，撞擊力令脫軌車廂完全脫離牽引纜。車廂繼而從約 50 米墮下，並倒在 2B 號塔旁的地上。

圖 13— 脫軌的 21 號車廂移位後到達 2B 號塔（左邊小圖詳細顯示吊架移位情況，右邊小圖顯示其正常位置）

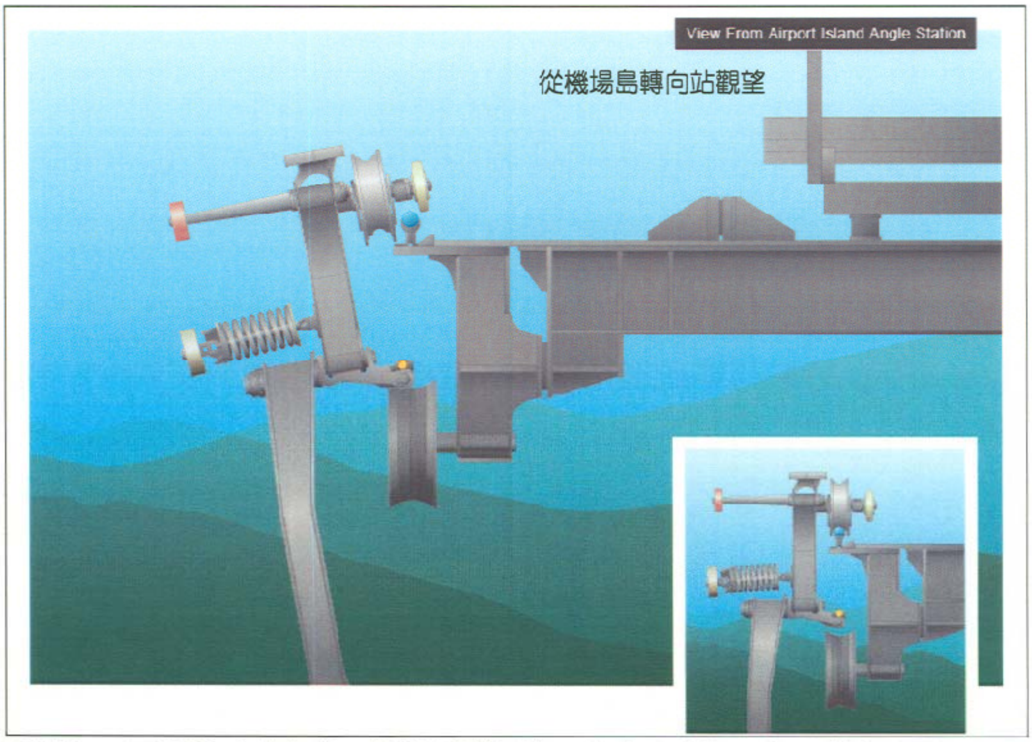


圖 14— 可拆除式夾扣與一組滑輪碰撞後，車廂即將墮下的一刻（小圖顯示吊架的正常位置）

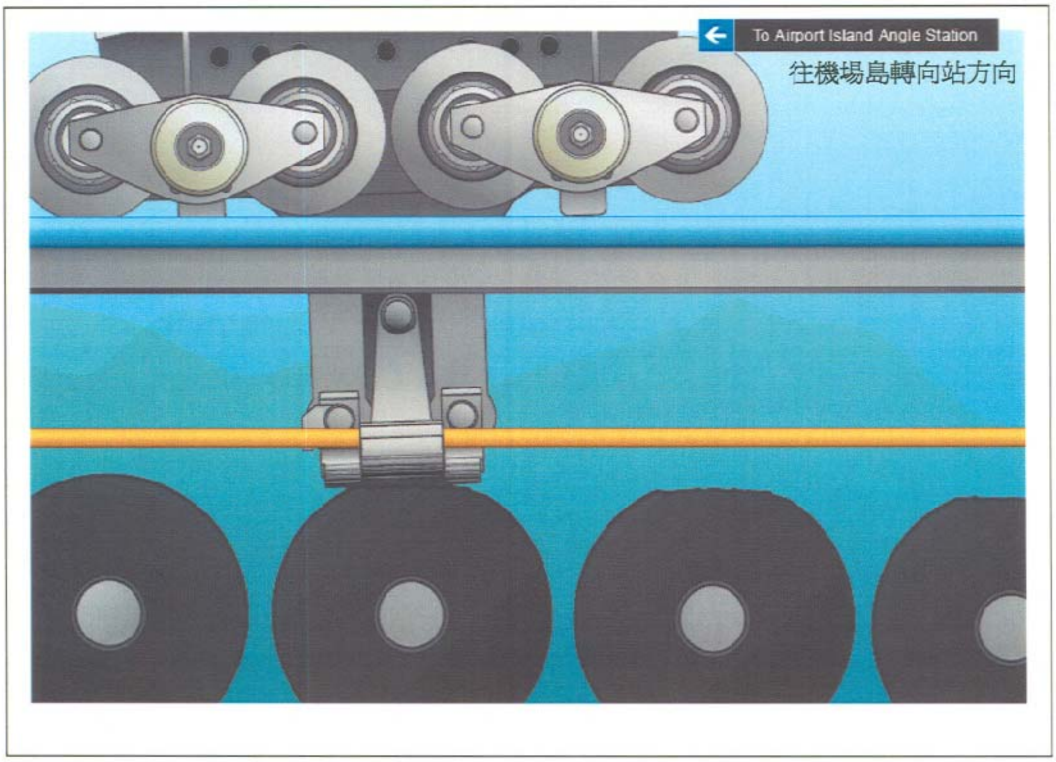


圖 15－ 可拆除式夾扣與 2B 號塔的滑輪踫撞，造成損毀

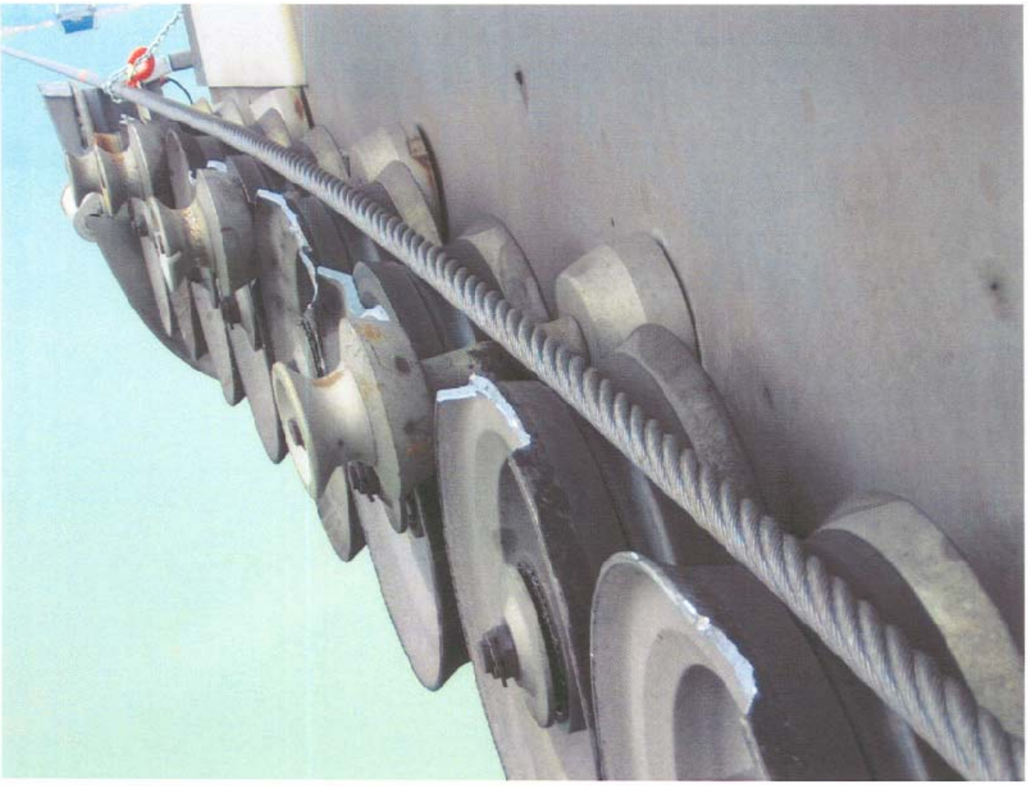


圖 16－ 踫撞後，2B 號塔的滑輪組受損，牽引纜已從捕纜裝置處放回原位

19. 有關 2007 年 6 月 11 日制動測試的詳細過程，以及牽引纜與車廂在制動測試中的動態特性分析，請參閱附件二。

結論

20. 專家委員會認為，在 2007 年 6 月 11 日年檢中，纜車制動系統操作不當，令纜車過急減速，減速率超過纜車生產商訂明的限度。減速令導軌纜及牽引纜垂直擺動，導致 21 號車廂脫離導軌纜。

21. 車廂墜下是脫軌的結果，而墜下乃因移位後的車廂吊架與 2B 號塔頂的滑輪組踫撞引致。

22. 必須指出，在纜車正常操行時，兩組制動器同時失靈的機會微乎其微。根據纜車設計，任何一組制動器的調節控制失靈，皆會自動觸發警報訊號，繼而引發受控的減速，制停纜車。Leitner 指出，在 2003 至 2006 年期間，該公司所裝設的 130 多個同類纜車系統，不論是單纜式或雙纜式系統，從未出現過兩組制動器同時失靈的情況。因此，在年檢中模擬兩組制動器同時失靈的制動測試是不必要的，而且在任何時候也不應該進行。

23. 專家委員會認為，即使在 19 時 39 分制動測試完畢後出現車廂局部脫軌情況，只要採取以下任何或全部措施，也可避免 21 號車廂脫纜墮下：

23.1 在纜車沿線特定位置派駐員工，觀察車廂及纜索的擺動情況。

23.2 在作出進一步行動前，審慎觀察監控及數據收集系統（SCADA）的減速數據及圖表。

23.3 入夜後應停止進行制動測試。

23.4 制動測試進行期間，發現減速過急時，立刻按照操作及保養手冊的指示，向纜車生產商的本地技術支援代表徵詢建議，以採取適當應變措施。

23.5 2B、3、4、5、6 及 7 號塔頂設有閉路電視，監察脫纜事故。若 2007 年 6 月 11 日黃昏 2B 號塔的閉路電視運作正常，21 號車廂進入 2B 號塔時的狀況便可及時察覺。

建議

24. 專家委員會建議以下補救措施，避免同類事故再次發生：

24.1 為纜車操作員及維修保養人員提供重溫課程，確保他們有足夠的技術認知，以進行纜車年檢。

24.2 為年檢的所有項目內的步驟及程序制定指引。

24.3 引進品質管理系統，確保纜車操作安全可靠，包括年檢。

24.4 每當纜車出現過急減速時，於系統重開之前必須進行目視檢查，察看是否有脫軌情況。

24.5 在制動測試進行期間，必須對整條纜車線道進行目視檢查，察看纜索或車廂是否有任何不正常的擺動。

24.6 不應同時進行的操作須施以聯鎖處理。例如，利用聯鎖確保在人手測試中不能同時操作兩組制動器，以模擬兩組調節控制同時失靈的情況。必須注意一點，制動器測試按鈕的聯鎖處理，在國際纜車業界並非標準的處理模式，但專家委員會認為，可保萬無一失的聯鎖設備是值得考慮的。聯鎖方案已獲纜車生產商接納。

24.7 建議機電工程署出席 ITTAB（國際纜車監管機構會議），與國際纜車同業分享有關經驗。

第二部分

對纜車設計、
操作、保養及管理
的評估

第二部分 - 昂坪纜車設計、操作、保養及管理的評估

評估方法

25. 專家委員會進行評估時採納的方法如下：

25.1 由海外專家對纜車進行實地檢查及審核；
25.2 檢討昂坪纜車自 2006 年 9 月 18 日起開放予公眾使用以來發生過的服務中斷事故及纜車營運機構的表現；
25.3 檢討機電工程署進行隨機巡查時觀察所見及得出的結果；
25.4 檢討昂坪纜車的操作記錄，包括故障記錄、員工值班、培訓及超時工作記錄；
25.5 查驗保養明細表、程序、施工指示、維修記錄及相關記錄；
25.6 就昂坪纜車操作及保養相關事宜，檢討與 Skyrail 有關員工、纜車製造商及擁有人代表的會面記錄，以及由該等人士提供的資料；
25.7 細閱由機電工程署於 2007 年 1 月及 TÜV SÜD 於 2007 年 5 月進行纜車表現檢討的報告;
25.8 檢討纜車營運機構的零件存貨及管理系統。

由海外專家對纜車進行實地檢查及審核

26. 在事故調查期間，海外專家亦對昂坪纜車進行了實地檢查及審核，觀察所見及得出的結果載於附件三。

檢討以往發生的服務中斷事故

27. 自從昂坪纜車於 2006 年 9 月起開放予公眾使用以來，共發生過 22 宗嚴重事故，導致服務經常中斷。這些事故惹來乘客大表不滿，並令公眾關注纜車系統是否可靠。

28. 如不計算惡劣天氣及初期系統不正確設定所導致的阻延，昂坪纜車曾發生：

– 三宗因組件設計缺陷導致的嚴重事故
– 十一宗因操作失誤、工作協調欠佳、手工差劣、操作警覺不足、保養欠佳及存貨管理問題導致的嚴重事故

29. 以下第 30 至 38 段乃專家委員會就昂坪纜車設計、操作、保養及管理的評估。

檢討與昂坪纜車設計有關的事故

30. 以下表一列出三宗因組件設計缺陷導致的服務中斷事故。

表一

參考編號	日期及服務中斷持續期間	事故簡述
D1	2006 年 10 月 8 日 服務中斷 58 分鐘	牽引纜與塔上的捕纜裝置軸之間的間隙不足，兩者因互相觸及而啟動接地故障警告。
D2	2006 年 10 月 15 日 服務中斷 55 分鐘	控制系統一件電氣零件耐用程度低，導致失靈，引致服務間歇受阻。
D3	2007 年 2 月 6 日 服務中斷 15 分鐘	於出車操作時錯誤計算車廂儲存庫內的車廂數目，導致服務延誤。

31. 專家委員會經仔細研究昂坪纜車的操作、設計藍圖及建造、控制安排、安全措施及選擇雙纜式系統的設計理念，認為昂坪纜車的設計符合主流的國際標準及慣例，在設計方面符合多項參數，包括乘客流量、地形局限、風速阻力及環境因素。

32. 另外，專家委員會注意到纜車系統的若干組件，包括車站內的 V 形皮帶滑輪、導軌纜、吊架與車廂之間的連接栓，均出現銹蝕，而啟用只一年的系統有此情況乃意料之外（見圖 17、18 及 19）。置於車廂儲存庫內的零件亦有銹蝕現象。該等組件應進行防銹處理，或改用質量較佳的物料，以適應香港的潮濕氣候，尤其是北大嶼山區域的潮濕環境。

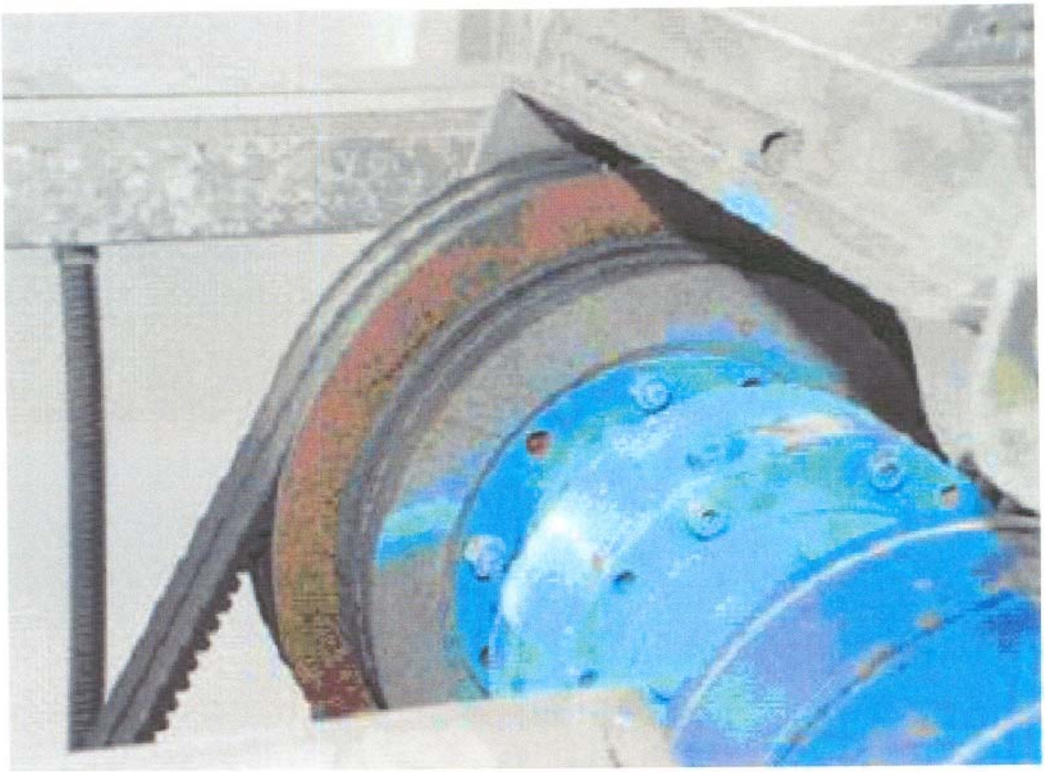


圖 17－ 銹蝕的 V 形皮帶滑輪

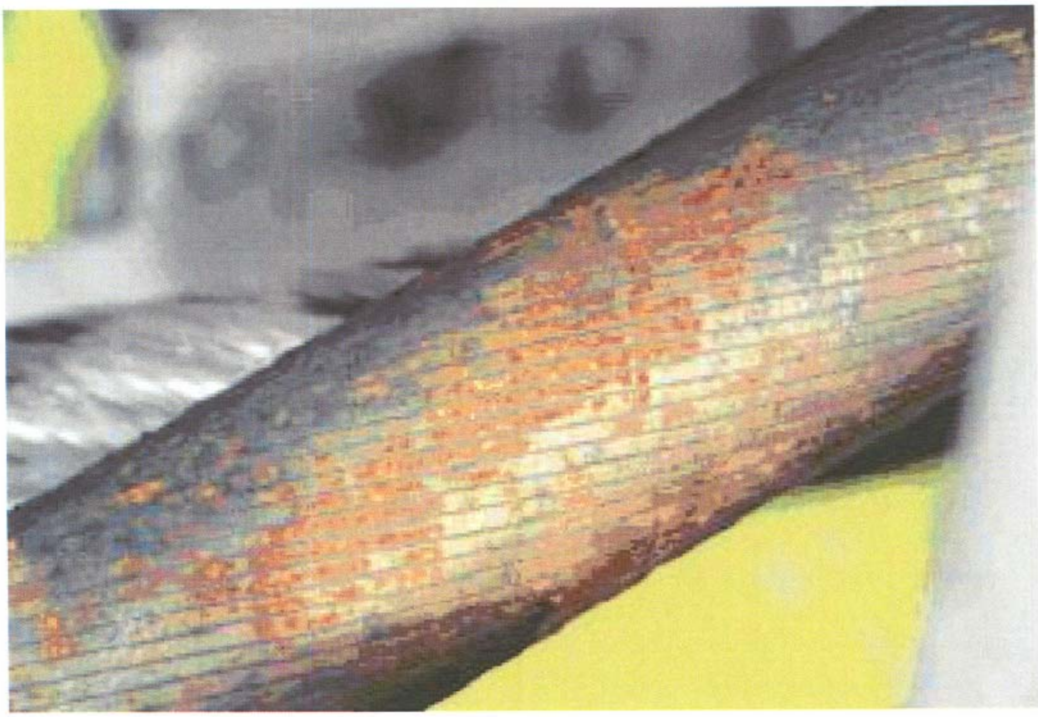


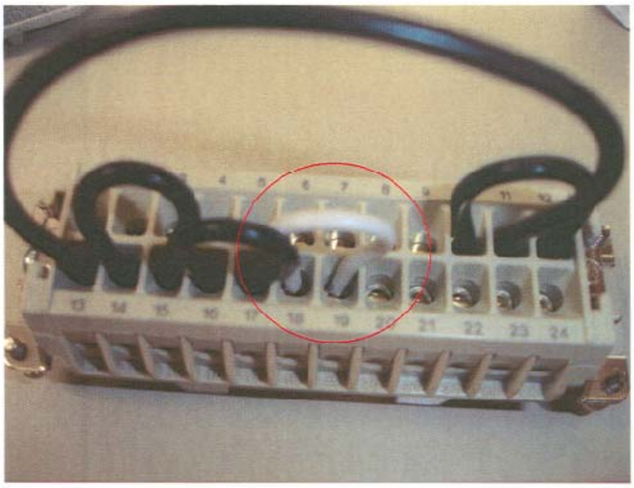
圖 18－ 銹蝕的導軌纜

圖 19－ 置於車廂儲存庫內出現銹蝕的零件

檢討與昂坪纜車操作、保養及管理有關的事故

33. 以下表二列出十一宗因操作失誤、工作協調欠佳、手工差劣、操作警覺不足、保養欠佳及存貨管理問題而導致的持續服務中斷事故。

表二

參考編號	日期及服務中斷持續期間	事故簡述
OM1	2006 年 9 月 30 日 服務中斷 51 分鐘	東涌車站使用不正確的控制作用插頭，令控制系統操作不當，導致系統失誤。  圖 20－插頭上的接線（紅圈顯示）被發現沒有接上
OM2	2006 年 10 月 15 日 服務中斷 59 分鐘	於晚間進行的保養工作引致纜車車廂距離失當，以致纜車未能於 2006 年 10 月 15 日早上如期運作。
OM3	2006 年 10 月 27 日 服務中斷 4 小時 20 分鐘	一個位於車廂儲存庫的驅動鏈輪卡住，令其中一個輪齒受損。由於沒有備用存貨，故須立即維修已損壞的鏈輪，令服務中斷超過 4 小時。  圖 21－驅動鏈輪的其中一個輪齒受損

OM4	2006 年 11 月 28 日 服務中斷 23 分鐘	一條摩擦皮帶鬆脫，令車廂分隔距離失當，導致系統失誤。皮帶張力檢查的頻密程度及調校不足。
OM5	2007 年 1 月 1 日 服務中斷 1 小時 12 分鐘	一個摩擦輪胎於操作中洩氣，導致系統失誤。輪胎氣壓檢查的頻密程度及調校不足。
OM6	2007 年 1 月 3 日 服務中斷 1 小時 18 分鐘	機場島轉向站一個電子編碼器有水滲入，導致系統失誤。編碼器的電子組件未能有效防潮及防垢。  圖 22－紅圈顯示在失靈的編碼器上發現水漬及油質污垢的位置
OM7	2007 年 1 月 17 日 服務中斷 6 小時 20 分鐘	有污垢的車站滑輪凝聚水氣，觸發接地故障警告，導致系統失誤。車站滑輪的檢查及清潔工作不足。
OM8	2007 年 2 月 7 日 服務中斷 26 分鐘	一條摩擦皮帶鬆脫，令皮帶驅動器打滑，導致系統失誤。皮帶張力檢查的頻密程度及調校不足。
OM9	2007 年 4 月 9 日 服務中斷 51 分鐘	一條摩擦皮帶鬆脫，令皮帶驅動器打滑，導致系統失誤。於調校皮帶張力時，技術人員過度上緊一枚調校螺栓，令螺紋損壞。其後須更換拉力螺栓，延長服務中斷時間。

OM10	2007 年 5 月 11 日 服務中斷 2 小時	一枚彈簧加壓減震滑輪於操作中損壞，導致系統失誤。減震滑輪軸表面呈現嚴重磨損，顯示定期檢查及保養不足。  圖 23－呈現嚴重磨損的減震滑輪軸
OM11	2007 年 6 月 11 日 服務由 19 時 52 分起中斷至今	第 21 號車廂在 2B 號塔位置墜下撞毀。事故因進行年檢時制動器操作失當造成。  圖 24－事故發生後的第 21 號車廂殘骸

34. 機電工程署自昂坪纜車正式啟用以來，一直緊密監察其安全表現。在過去九個月，機電工程署曾向 Skyrail 提供指引及建議，以提高纜車的可靠性。建議的原因乃根據兩類別而提出，分別為調查各服務中斷事故的觀察所得，及機電工程署進行隨機巡查的觀察所得。從以下表三及表四可見，機電工程署除履行監管角色外，更仔細檢視纜車操作及保養。

表三－機電工程署調查各服務中斷事故後所提出的改善建議

（*有關改善項目已由 Skyrail 在機電工程署緊密監察下完成）

參考編號	事發日期	向 Skyrail 提出的建議／Skyrail 採取的行動
OM1	2006 年 9 月 30 日	• 確保搖控控制台的所有功能插頭上的接線接駁妥當；* • 恰當地以文件證明及執行工程轉變。*
D1	2006 年 10 月 8 日	• 為 3 號塔的捕纜裝置軸加設尼龍套作為臨時措施；* • 向 Leitner 跟進重新設計捕纜裝置，以加寬捕纜裝置軸與牽引纜之間的間隙；* • 重新編配 3、4 及 7 號塔的閉路電視位置，以加強監察塔身四周的纜車狀況。*
OM2	2006 年 10 月 15 日	• 以正確方法在導軌纜上塗上潤滑油，令纜車系統可於翌日早上如期順利開放運作。*
OM3	2006 年 10 月 27 日	• 儲存 4 號鏈帶的備用鏈輪；* • 在本地採購鏈輪，作為後備供應；* • 要求 Leitner 確定車廂輸送系統符合適當的負荷水平，以及所有零件符合設計應用規格；* • 為車廂輸送系統設置電動機扭力限制器；* • 為車廂輸送系統的電腦化操作設定人手跨控功能；* • 為監控及數據收集系統 (SCADA) 加設輸送系統操作電流顯示器；* • 要求 Leitner 研究出車或收車操作期間纜索交疊的原因及相應的改善措施；* • 在實驗室對損壞了的鏈輪進行化學及機械特性測試，並在有需要時採取適當措施；* • 檢討車廂儲存庫的輸送系統，以提高服務可用性。*
OM5	2007 年 1 月 1 日	• 建立記號系統以辨別洩氣的摩擦輪胎；* • 設計及提供輪胎洩氣檢查設施；* • 所有摩擦輪胎加設輪胎氣壓計；* • 採取防止輪胎樞軸螺栓銹蝕的措施；* • 定期檢討摩擦輪胎氣壓設定；* • 檢視於輪胎氣壓降低的情況下，「車廂碰撞」警告訊號與隨之出現的「最低夾扣力」警告訊號之間是否有連帶關係。*
OM6	2007 年 1 月 3 日	• 提高保養編碼器及其他室外電子裝置的頻密度；* • 檢討室外設備的保護裝置是否適用；* • 制定防止冷凝水影響編碼器的措施。*

OM9	2007 年 4 月 9 日	• 改善記錄日常保養工作的記錄系統；* • 提高檢查分隔裝置的固定螺栓的頻密度，並採取適當措施防止固定螺栓鬆脫（如使用螺紋膠）；* • 為保養隊伍安排技術重溫課程，覆習正確的回復程序；* • 提供適用於分隔裝置的可調螺栓的鎖定螺母及墊片。*
OM10	2007 年 5 月 11 日	• 檢查所有彈簧加壓減震滑輪的對準及操作情況；* • 確保備存有足夠的彈簧加壓減震滑輪備用零件； • 定期潤滑及檢查彈簧加壓減震滑輪的活動組件及其他類似機件。

<u>表四－機電工程署進行隨機巡查時建議改善的事項</u>

（*有關改善項目已由 Skyrail 在機電工程署緊密監察下完成）

參考編號	日期	觀察所得／向 Skyrail 提出的建議
1	2006 年 7 月 31 日	觀察所得：新聘請的保養技工於纜車操作時單獨處理故障。 建議內容：加強實地監察保養工作，確保故障能有效復修。*
2	2006 年 8 月 2 日	觀察所得：導軌纜的外層纜支移位。 建議內容：緊密監察外層纜支移位的導軌纜，確保纜索完整。*
3	2006 年 9 月 17 日	觀察所得：車廂門鎖促動裝置出現銹蝕。 建議內容：更換原有的車廂門鎖觸動裝置，改用不銹鋼質的促動裝置。*
4	2006 年 10 月 10 日	觀察所得：於操作時主電動機編碼器發生故障，但沒有可供更換的備用編碼器。 建議內容：確保有適量存貨，並及時補充主電動機備用編碼器。*
5	2006 年 10 月 15 日	觀察所得：自開放予公眾使用以來頻頻發生車廂距離故障。 建議內容：記錄及分析車廂間隔距離，改善防撞警告軟件。*
6	2006 年 10 月 15 日	觀察所得：接近開關器的連接埠嚴重腐蝕。 建議內容：接近開關器使用較長的電線，避免使用容易腐蝕的插頭及插座。*
7	2006 年 10 月 16 日	觀察所得：操作員錯誤申報最後載客車廂，存在停駛後乘客被困車廂的危機。 建議內容：提醒所有控制員及操作員遵守正確的「申報最後載客車廂」的程序。*

8	2006 年 11 月 3 日	觀察所得：更換銹蝕滑輪由 Leitner 負責進行，Skyrail 參與工作不多。 建議內容：- 緊密監察所有車站及轉向站的銹蝕滑輪更換工作； - 檢查是否有過分損耗的皮帶及滑輪；* - 為車站及轉向站加速/減速系統上的皮帶加裝張力調節器。*
9	2006 年 11 月 16 日	觀察所得：4 號塔的風速計失靈。 建議內容：重新啟動 4 號塔風速計的功能，以提供必需的風速測量。*
10	2007 年 1 月初	觀察所得：Skyrail 實行一個名為 FRACAS （故障報告分析及修正行動系統）的軟件管理系統，但未能充分善用。 建議內容：Skyrail 定期使用 FRACAS 進行故障分析，確認盡量減少服務中斷的措施。*
11	2007 年 1 月 5 日	觀察所得：一枚用作把救援驅動器接合上或分離於主驅動輪的螺栓損壞，該螺栓懷疑早已損壞，有員工注意到有關情況但未有向管理層報告。 建議內容：- 制定適當措施，檢查連接主軸的主驅動輪的分離狀況；* - 加強故障記錄及匯報制度。*
12	2007 年 3 月	觀察所得：更換銹蝕連接栓由 Leitner 負責進行，Skyrail 參與工作不多。 建議內容：提醒 Skyrail 密切監察更換工作，辨別任何不正常的情況。*
13	2007 年 4 月 30 日	觀察所得：一個車站滑輪的輪緣嚴重損壞，調查發現車站滑輪的一枚固定螺栓於纜車操作中損壞。 建議內容：定期檢查及更換車站滑輪所有出現銹蝕的固定螺栓。

35. 縱使昂坪纜車的營運機構須對該纜車系統的安全及可靠性負責，昂坪纜車擁有人地鐵有限公司（地鐵公司）亦須負上同等責任。於 2007 年初，昂坪纜車的表現明顯需要其擁有人的密切關注，機電工程署遂匯編了一份文件（附件四），列舉由多次事故及隨機巡查所得的觀察，並提出多項建議，包括地鐵公司應對昂坪纜車進行表現檢討。

36.　　其後，地鐵公司以合約形式委託 TÜV SÜD 進行獨立查核，並於 2007 年 5 月提交有關報告（附件五）。縱使昂坪纜車於初期運作期間，可靠性符合同類系統的最高標準，報告仍列出數個需要改善的範疇。與 ISO 9000 質量管理系統的獨立審核比較，部分不足之處可界定為非符合水平項目。

37.　　機電工程署曾對服務中斷事故進行調查，亦曾對纜車進行隨機巡查（見表三及表四）。根據以上的調查及觀察所得，纜車在操作、保養及管理方面的整體表現仍有改善空間。

38.　　專家委員會因此認為，纜車應就以下各方面作出改善：

38.1　訓練操作人員及維修保養人員

操作人員及維修保養人員需要接受技術重溫訓練，加強技術認知，確保纜車能提供高度可靠的纜車服務，以符合公眾的期望。要注意的是，加強對緊急事故的準備工作，改善對突發事件的應變，以應付惡劣天氣、意外停駛、意外事件，以及爭分奪秒的故障復修。另外，要加強操作隊伍與保養隊伍之間的溝通、諒解和合作，確保操作隊伍觀察所得能即時向保養隊伍報告，反之亦然。

38.2　保養及操作的程序與施工指引

除製造商提供的操作及保養手冊外，操作人員及保養人員亦應熟悉詳細的程序及施工指引，以便應付日常操作及保養工作。這些文件應按照操作及保養手冊相關部分互相參考，以備隨時派發給所有有關員工。為了令員工更容易明白，這些程序及施工指引應視乎適用程度以中文編寫。檔案控制系統應符合 ISO 9000 或同等質量管理系統的水平。

38.3　備用零件及物料庫存控制

應檢討重要備用零件及物料現有的存貨量。宜建立庫存管理系統，顧及備用零件的付運時間及損耗率，以保持足夠的備用零件及物料存貨。另外，亦應檢討是否須在每個總站或車站存放備用零件，以提升復修故障的反應時間。

38.4 有計劃的預防式保養

鑑於系統多個部分，如制動碟、導軌纜、車站滑輪、車廂吊架等，均出現不同程度的銹蝕現象，應加強有計劃的預防式保養。此外，亦應增加例行檢查及系統組件保養的頻密度，防止因組件故障而令服務長時間中斷。

另外，據觀察所得，纜車系統平均每月的運行時間為 420 小時，比製造商建議的上限 250 小時為多。製造商以此上限為基準，制定建議的維修保養程序。由於使用量增多，有關方面應諮詢製造商，考慮參照現時較長的運行時間，重新制定維修保養的頻密度。

38.5 質量管理

截至 2007 年 7 月底，仍未建立質量管理系統，令公司的操作及保養工作面對不一致的風險，導致纜車屢次出現操作失誤，而若干個案因工作質量低於標準，影響纜車的可靠性。建立及執行架構完善的質量管理系統，有助纜車服務更安全、更可靠。

38.6 人力資源管理

操作人員及維修保養人員採用 12 小時一更的輪班制。此外，他們更須經常加班，工作時數增加，難免會令工作質量下降。例如，在 2007 年 4 月，保養隊伍的總加班時數為 580.5 小時，結果令每名維修保養人員實際上採取了 14 小時一更的輪班制。

值得一提的是，車廂大修有待成為日常工作之一。保養隊伍人力短缺的問題，於車廂大修工程開始時會更見嚴重。

自纜車系統於 2006 年 9 月投入服務，維修保養隊伍有四名主要員工相繼離職（隊中共有 27 名員工）。維修保養隊伍應不斷加強及保持員工的知識及技術水平。

38.7 採購常規

服務、工具、物料及備用零件的採購未有妥善安排優次，導致維修保養工作延誤，影響纜車服務的可靠性。表五列出了採購處理時間過長的例子。當務之急是檢討採購常規，管理層亦應參與及制定優先次序，讓維修保養隊伍能及時獲得有關服務、工具、物料及備用零件。此外，亦須開拓其他備用零件及物料供應來源。

表五

項目	採購處理時間	後果
1. 維修塔上的閉路電視	自 2007 年 5 月至今	未能有效監視及察覺塔上出現的任何脫纜故障
2. 採購彈簧加壓車站滑輪的備用軸	自 2007 年 5 月至今	如果受損的軸能及時更換，2007 年 5 月 11 日發生的事故是可避免的，因為事故發生前已有人察覺該軸受損。
3. 採購用於站內高空工作的工作台	約 3 個月	工作台運抵之前，高空工作無法順利進行。
4. 採購夾扣力度測試器	採購至今已超過 6 個月	車廂大修無法按時進行。
5. 採購 V 形皮帶張力裝置	約 1 個月	張力裝置運抵之前，故障復修無法按時進行。

第三部分

纜車重新開放予公眾使用
的先決條件

第三部分 - 纜車重新開放予公眾使用的先決條件

39. 經檢討發生於 2007 年 6 月 11 日的車廂墜下事故，考慮到現行法例、國際標準及業內常規、獨立檢測員提供的意見，以及自 2006 年 9 月起纜車的操作及保養情況，專家委員會對重新開放纜車予公眾使用提出以下先決條件：

39.1 檢查纜車所有因車廂墜下事故而造成的損壞部分，如有必要，須進行維修及更換，並由製造商對有關系統或組件提交證明。檢查工作包括：

(a) 纜索製造商負責檢驗導軌纜；

(b) 纜索製造商負責檢驗牽引纜；

(c) 註冊結構工程師檢驗塔架結構，另外檢查塔架架身的準繩偏差狀況；

(d) 纜車製造商檢驗已更換的 2B 號塔組件。

39.2 根據架空纜車（操作及保養）規例第 20(3)條檢驗纜車系統如下：

(a) 檢查所有纜索，包括量度圓周、用目視檢查運載拖纜、牽引纜及導軌纜的全長及使用鋼纜探傷儀錄取該等纜索的全長的讀數；

(b) 檢查車廂吊架及夾扣，包括開動及檢測裝置；

(c) 檢查在支架上的滑車輪輪列、滑車輪、襯套、銷及楔；

(d) 檢查位於各車站的進入及離開的輪列的滑車輪、襯套及銷；

(e) 檢查主要、輔助及後備驅動器及制動系統；

(f) 檢查所有電路、控制裝置、開關裝置及接地裝置；

(g) 檢查車廂門鎖裝置和車廂的變形、已破損或鬆脫的車窗及隙縫的大小；

(h) 檢查支架及地基，包括在支架頂端的以轉矩收緊的螺栓；

(i) 檢查車廂及纜索速度同步設備；及

(j) 機電工程署要求檢驗的任何其他器具、裝置或機器。

39.3 如新裝設的系統般，測試及調試以下纜車組件及操作程序：

(a) 檢驗所有車廂，包括夾扣、車門機件、車架及滑輪，以及結構部分；

(b) 檢驗驅動、制動、纜索張力裝置；

(c) 檢驗所有控制系統、安全裝置、感應器及警鐘；

(d) 檢驗出車及收車系統、車廂運輸及儲存系統；

(e) 檢驗閉路電視及所有其他監察系統。

39.4 執行所有 TÜV 獨立查核報告內提出的改善措施，從而提高系統可靠性。

39.5 提交有關組織管理、操作及保養工作的建議書，簡介新的管理方案如何令纜車有效操作，符合安全及可靠性的要求，並使纜車服務滿足公眾期望。

39.6 採納 ISO 9000、PAS 55 或同等的質量認證系統，以操作及保養纜車。當員工培訓工作完成後，認證系統應正式生效。以下各方面宜多加注意：

(a) 編訂保養程序及施工指引、操作核對清單、活動日誌，並確保上述各項能有效執行；

(b) 實施恰當的備用零件存貨/庫存系統；

(c) 為所有合資格的人、控制員、操作員、保養技術員及新入職員工提供針對式培訓或重溫課程。有關方面應遞交訓練計劃，確保操作人員及維修保養人員定期接受有關訓練。

- 完結 -

專家委員會
香港特別行政區政府昂坪纜車車廂墜下事故調查報告
2007 年 7 月 30 日

附件一

政府化驗所科學鑑證結果

Lab. No.: ROS1759/1760

ANALYTICAL REPORT

GOVERNMENT LABORATORY
HONG KONG
7/F, Homantin Government Offices
88 Chung Hau Street, Kowloon

.....2..... c

Date: 24 July 2007

Item(s) for Examination : - Ngong Ping Skyrail
Incident happened on 11 June 2007
Identification of the grease dirt

Sample Description : - Dirt inside a plastic bag, and reference lubricant in glassware

Marks :- memo ref. (15) in EM/GL/03/10 SF11(A17)b

Received from : - Director of E&M Services

Received on : - 18 July 2007

Method Reference : - GC-MS

Date of Analysis : - 18 – 24 July 2007

RESULTS OF EXAMINATION

The dirt was found to contain hydrocarbons. Similar hydrocarbons were also found in the reference lubricant sample.

Dr. W H FUNG
Chemist

Director of E&M Services
(Attn.: William SHUM)

G.L.1

********end of report********

(15)

By Hand

MEMO

From DEMS	To Government Chemist
Ref. (15) in EM/GL/03/10 SF11(A17)b	(Attn.: Mr. FUNG)
Tel. No. 2808 3547	Your Ref. in
Fax. No. 2577 4901	Dated Fax. No. 2714 4803
Date 18 July 2007	Total Pages 1

Ngong Ping Skyrail
Incident happened on 11 June 2007
<u>Identification of the grease dirt</u>

During the investigation of the incident, we have collected some grease dirt from the cabin #21 (on the surface of the front station roller shaft). We suspect the dirt was the lubricant of the track rope of the cable car system. Therefore, I write to seek your assistance in analysing the dirt.

2. Grease lumps collected from the cabin #21 are enclosed in the attached plastic bag. A sample of the lubricant of the track rope, contained in glassware, is also attached for your reference.

3. Please note that we are liaising with the cable car company to provide information on the chemical composition of the lubricant, which shall be send to you once available.

4. This part of our wok work (Regulatory Services) is not under the Trading Fund and this request is not chargeable to the EMSD Trading Fund.

(William SHUM)
for Director of E&M Services

encl.

GOVERNMENT LABORATORY HONG KONG

Dr. WH Fung
18/7/2007

Lab. No.: ROS1761/1762

ANALYTICAL REPORT

GOVERNMENT LABORATORY
HONG KONG
7/F, Homantin Government Offices
88 Chung Hau Street, Kowloon

.....2..... c

Date : 24 July 2007

Item(s) for Examination : - Ngong Ping Skyrail
Incident happened on 11 June 2007
Identification of the grease dirt

Sample Description : - Grease dirt sample inside a plastic bag marked 3D and, grease dirt sample inside a plastic bag marked 2U.

Marks :- memo ref. (16) in EM/GL/03/10 SF11(A17)b

Received from : - Director of E&M Services

Received on : - 19 July 2007

Method Reference : - GC-MS

Date of Analysis : - 19 – 24 July 2007

RESULTS OF EXAMINATION

The samples marked 3D and 2U respectively were found to contain hydrocarbons. Similar hydrocarbons were also found in the reference lubricant sample delivered to the Government Laboratory on 18 July 2007.

Dr. W H FUNG
Chemist

Director of E&M Services
(Attn.: William SHUM)

G.L.1

********end of report********

16

By Hand

MEMO

From DEMS	To Government Chemist
Ref. (16) in EM/GL/03/10 SF11(A17)b	(Attn.: Dr. W H FUNG)
Tel. No. 2808 3547	Your Ref. in
Fax. No. 2577 4901	Dated Fax. No.
Date 19 July 2007	Total Pages 1

Ngong Ping Skyrail
Incident happened on 11 June 2007
<u>Identification of the grease dirt</u>

Further to the memo dated 18 July 2007 of even series, we have collected additional samples of the grease dirt found on the cabin #21 with details as follows :-

(a) Samples inside the plastic bag marked with "3D" were collected from the surface of front station roller (i.e. downhill side);

(b) Samples inside the plastic bag marked with "2U" were collected from the surface of rear station (i.e. uphill side).

2. We suspect the dirt was the lubricant of the track rope of the cable car system, a sample of the lubricant of the track rope was sent to you on 18 July 2007.

3. Please assist to analyze the dirt.

19 JUL 2007 Dr. W H Fung

GOVERNMENT LABORATORY HONG KONG

(William SHUM)
for Director of E&M Services

encl.

<u>附件二</u>

Oplatka 教授及 Nejez 教授
分析 2007 年 6 月 11 日制動測試的結果，
以及纜索的動態特性

Input to Report from the Expert Panel

Ngong Ping Skyrail Incident
on 11 June 2007

Authors:
Prof. Dr. Gabor Oplatka
and
Prof. Dr. Josef Nejez,

29. July 2007

Input to Report from the Expert Panel

Ngong Ping Skyrail Incident
on 11 June 2007

ordered by:

Electrical and Mechanical Services Department (EMSD)
Government of the Hong Kong Special Administration Region
3 Kai Shing Street, Kowloon, Hong Kong

ordered from:

Prof. em. Dipl.-Ing. Dr. Dr. h.c. Gabor Oplatka
Zweiackerstraße 34
8053 Zürich
SWITZERLAND

and

Univ.-Prof. Dipl.-Ing. Dr. techn. Josef Nejez
General court-appointed expert for the field of ropeways
Bruckhaufner Hauptstrasse 15
1210 Wien
AUSTRIA

Date of report: 29th July 2007
Number of pages: 16
Number of supplements: 8

Contents

Supplements:

1. Mechanical Test & Commissioning (T&C) Report
   Braking Tests – Operating Conditions (page 72)
   Attachment 5.1.2.1 with 4 diagrams
2. Final Operating & Maintenance (O&M) Manual
   Part: B) 4.7 – Service Brake
   Chapter 5.9 Brake tests (annually) (page 15 and 16)
3. Witness Statement of [redacted]
   Including: Brake test and preliminary statement
4. Witness Statement of [redacted]
5. Witness Statement of [redacted]
6. Rope Calculation
   Section II, Chapter 11 (page 161-163)
   Proof of lifting off the carriage
7. Relevant Regulations
8. List of some dynamic incidents that led to crash of a vehicle

1 Introduction

On Monday 11 June 2007 at 7:52 pm an incident occurred at the Ngong Ping Skyrail: after the closing of public operation, a cabin derailed and fell down from the line at tower 2B during brake tests.

EMSD asked the authors of this report

- to examine and identify the causes of the incident and
- to submit a report with conclusions and recommendations to the Government.

This report is based on

- the documents made available to us,
- the observations and tests on site and
- the various rounds of talks.

We can report the following findings.

Preface:

- Our report is neutral, without consideration for any interests and is based on state of the art knowledge.
- We limit our report to the technical part of the questions in connection with the events on 11. 6. 07. Legal as well as other technical problems of the ropeway are not treated.

2 Findings

2.1 Sequence of events leading to the incident

2.1.1 Brake Tests

On 11 June 2007 brake tests were conducted after close of public operation in the context of the annual survey inspections. The installation was loaded with empty cable cars over a distance of 122.4 m. The testing speed for the brake tests was 7.0 m/s.

The following kinds of braking are available:

- electrical braking,
- braking with service brake system,
- braking with emergency brake.

Service brake can be applied

- normal (deceleration 0.40 m/s^2),
- fast (deceleration 0.75 m/s^2),
- uncontrolled (equivalent to "unmodulated").

(The system of service brake – especially that it consists of two independent groups of service brakes with independent modulation units – is considered to be well known to EMSD, therefore no detailed description seems to be necessary. A complete description is provided in Final Operation & Maintenance (O&M) Manual, Part: C) 1.2: Reference Manual Electrical Equipment. According to Leitner the terms "uncontrolled" and "unmodulated" are used equivalently).

Table 1 shows the operating conditions of the brake tests, as follows:

- Column 3: as performed during the commissioning of the Ngong Ping Skyrail on 16. 5. 06, see also supplement 1,
- Column 4: as scheduled for the annual survey inspections in O+M Manual, see supplement 2,
- Column 5: as performed during the annual brake tests on 11. 6. 07, day of the incident.

Table 1: Brake Tests Operating Conditions, 122.4 m, Empty Carriers, v = 7.0 m/s, Section II only, deceleration rates (a) in m/s^2

Nr.	Type of braking	16.5.06	O+M Manual	11.6.07
1.	Electrical braking by motor with „Stop“	a = 0.40	-	time: 7:21 pm a = 0.44
2.	Electrical braking by motor with „Fast Stop“	a = 0.60	-	time: 7:25 pm a = 0.56
3.	Mechanical braking by service brake, controlled, normal deceleration	a = 0.42	„Stop service brake“ a = 0.40 ± 0.02	time: 7:29 pm a = 0.42
4.	Mechanical braking by service brake, controlled, fast deceleration	a = 0.74	-	-
5.	Mechanical braking by service brake, uncontrolled (1 group), normal deceleration	a = 0.80	-	
5B.1	Mechanical braking by service brake, uncontrolled (2 groups), normal deceleration	-	-	time: 7:36 pm first as at 7:39 pm (5B.2), a = 2.5 then as at 7:29 pm (3), a = 0,45
5B.2	Mechanical braking by service brake, uncontrolled (2 groups), normal deceleration	-	-	time: 7:39 pm first a = 2,5 finally a = 1,0 average a = 1,5
5C	Mechanical braking by service brake, uncontrolled, fast deceleration	n. a. (not applicable)	-	-

6.	Mechanical braking by emergency brake, controlled, normal deceleration	a = 0.40		-

Looking at the data of Table 1 and analyzing the procedure of the brake tests the following facts are remarkable:

- The first three tests of 11. 6. 07 – brake test No. 1 (7:21 pm), brake test No. 2 (7:25 pm) and brake test No. 3 (7:29 pm) – (diagrams 1, 2 and 3) produced almost identical results as the equivalent tests of 16. 5. 06.

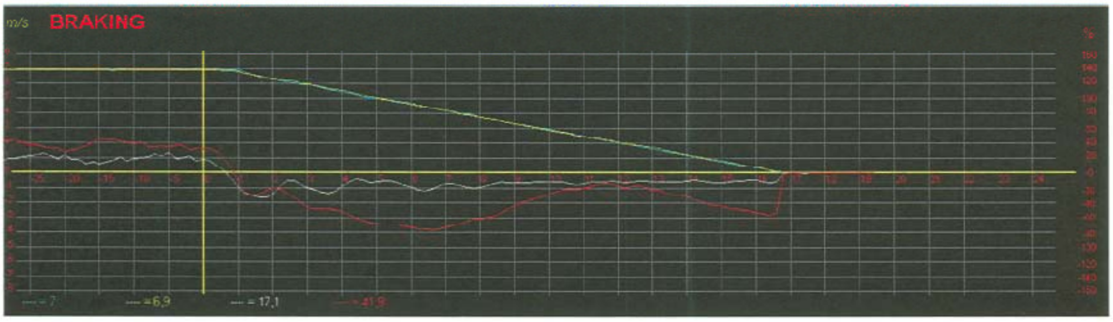


Diagram 1: Electrical braking by motor with "Stop" (brake test No. 1, 11. 6. 07)

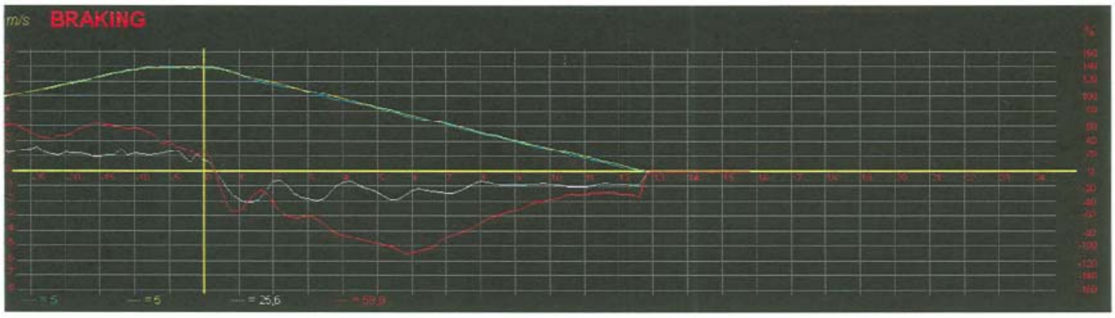


Diagram 2: Electrical braking by motor with "Fast Stop" (brake test No. 2, 11. 6. 07)

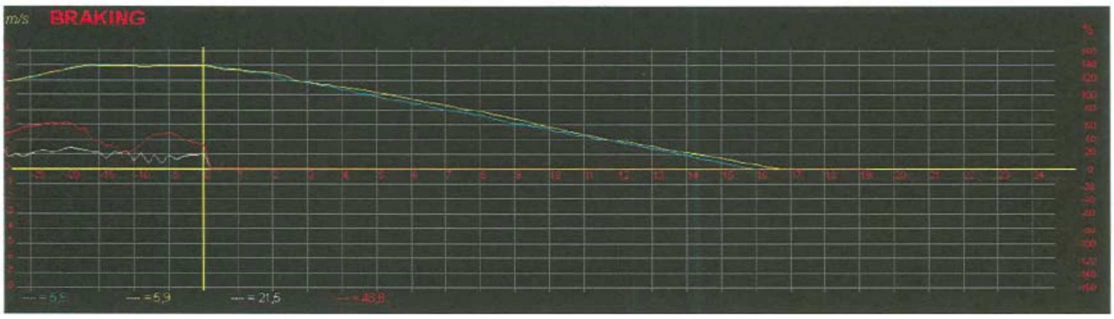


Diagram 3: Mechanical braking by service brake, controlled, normal deceleration (brake test No. 3, 11. 6. 07)

- In O+M Manual only service brake test No. 3 (7:29 pm) is required for the annual brake tests.
- Brake test No. 4 of commissioning on 16. 5. 06 was not performed on 11. 6. 07.
- At 7:36 pm an attempt was made to perform an uncontrolled service brake stop according to brake test No. 5 of commissioning (mechanical braking with service brake, uncontrolled, normal deceleration). The maintenance technician pressed four pushbuttons on the test console (Fig. 1) for an uncontrolled stop of all service brakes, but only for approximately 0.5 s – the switching cubicle had to be opened for that purpose. Therefore the initial uncontrolled braking with approximately 2.5 m/s^2 was followed by a controlled stop with linear deceleration as in brake test No. 3 (7:29 pm), with an average of approximately a = 0.4 m/s^2 (see No. 5B.1 in Table 1, diagram 4).

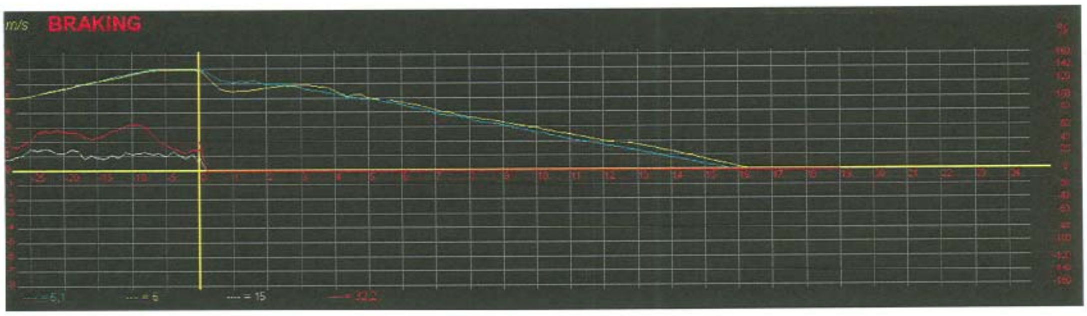


Diagram 4: Mechanical braking by service brake, uncontrolled (four pushbuttons) for approximately 0.5 s, afterwards controlled, normal deceleration (brake test No. 5B.1)

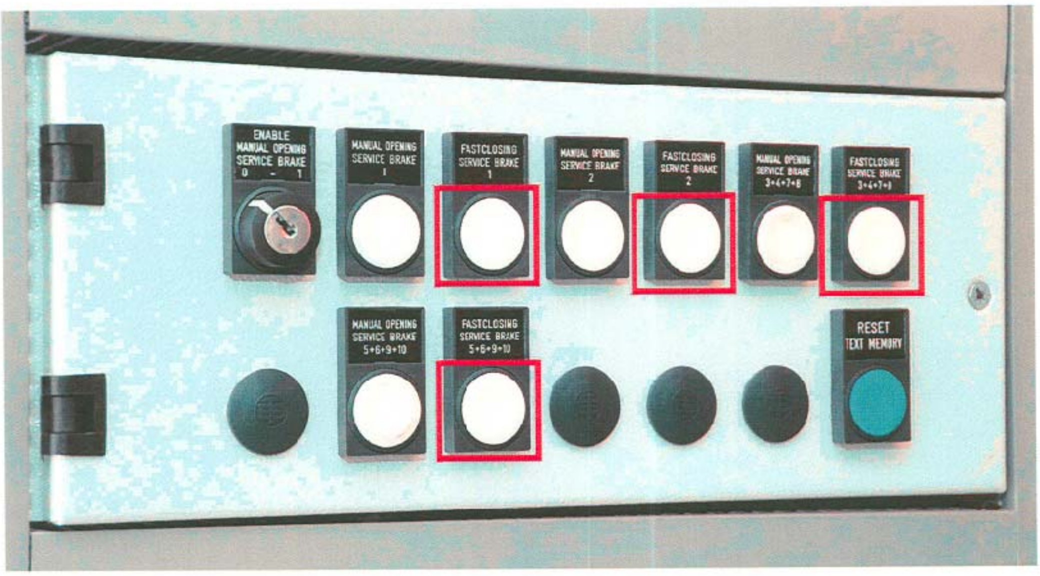


Fig. 1: Test console for service brakes inside the switching cubicle. The four buttons marked red are characterized as "FAST CLOSING SERVICE BRAKE 1", "FAST CLOSING SERVICE BRAKE 2", "FAST CLOSING SERVICE BRAKE 3+4+7+8" and "FAST CLOSING SERVICE BRAKE 5+6+9+10". The function of the pushbuttons when pressed is to close the relevant service brakes immediately without any modulation.

- Because of the low deceleration rate (0,45 m/s^2) of brake test No. 5B.1 (7:36 pm) this test was judged as invalid. Obviously nobody took care of the difference between the braking diagrams of brake test No. 3 (7:29 pm) and brake test No. 5B.1 (7:36 pm) with its high deceleration rate of approximately 2.5 m/s^2 at the beginning of the braking (see diagram 4).
- At 7:39 pm brake test No. 5B.1 was repeated but with pressing the four pushbuttons pressed during the whole braking time. This resulted in the sharpest possible braking with a braking time of approximately 5 s. The initial deceleration was 2.5 m/s^2, at the end of braking it was still 1.0 m/s^2 and on average approximately 1.5 m/s^2 (see Nr. 5B.2 in Table 1, diagram 5).

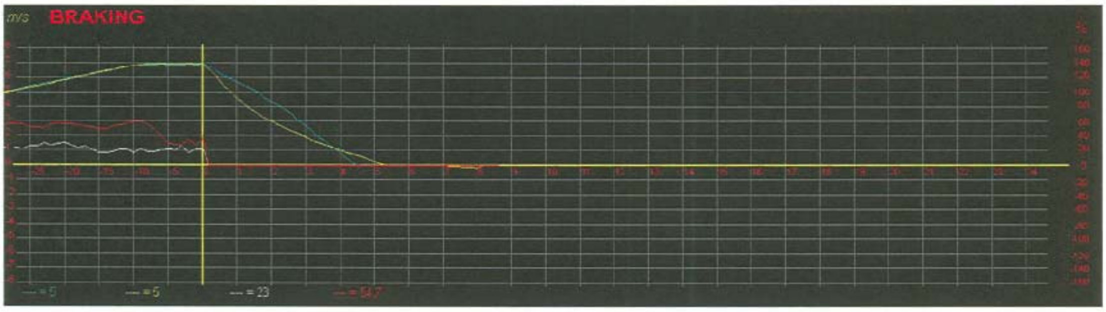


Diagram 5: Mechanical braking by service brake, uncontrolled (four pushbuttons)

- A survey of the brake tests of 11. 6. 07 of [redacted] is given in supplement 3.
- The discussions during the brake tests and the procedure after the incident following these tests are given in the witness statements. These include the above mentioned survey of the brake tests and a preliminary statement of [redacted] (see supplement 3) and the witness statement of [redacted] (see supplement 4). A witness statement of [redacted], who conducted the brake tests during commissioning is provided in supplement 5.

2.1.2 Derailment and the crash of cabin 21

The sharp braking of brake test 5 (diagram 5) caused a partial derailment of cabin 21 because of the dynamic effects emerging on both the hauling and carrying ropes. This was not observed by anybody. No grounding signal of hauling rope was observed.

Continuing the brake tests several restart attempts failed because of spatial displacements of cabins in Ngong Ping Terminal and Nei Lak Shan angle station.

The next attempt to restart the ropeway at 7:51 pm seemed to be successful. During the acceleration phase there came an automatic stop (electrical braking) at approximately 5.0 m/s, initiated from tower 2B and a grounding signal of hauling rope followed.

Searching for the cause of the stop the crash of cabin 21 at tower 2B was detected. The exact way cabin 21 failed to pass tower 2B and how it fell to the ground is of no great importance for the whole incident. Considering the evidence of the traces found and the conclusions drawn the description by [redacted] (see supplement 3) and by the "Ngong Ping 360 Incident Report" of Skyrail ITM of the way the incident happened can be accepted by and large.

3 Considerations

3.1 Why did cabin 21 get derailed?

The physical reason for the derailment of vehicle 21 was the brake test No. 5B.2 performed at 7:39 pm. The dynamic forces caused by the high deceleration of 2.5 m/s^2 led to lifting the carriage of cabin 21 off the carrying rope with the derailment following.

The input of energy caused by the high deceleration produced various dynamic effects, such as the following.

The deceleration of the hauling rope caused a series of oscillations:

- longitudinal wave in the hauling rope followed by deceleration of the vehicles,
- the deceleration of the vehicles produced a longitudinal oscillation of the vehicles
- the longitudinal oscillation of the vehicles produced a transverse wave in the carrying rope,
- the transverse wave in the carrying rope produced a vertical oscillation of the vehicles;
- the deceleration of the hauling rope also produced a transverse wave in the hauling rope,
- the transverse wave of the hauling rope produces a vertical oscillation of the vehicles.

The rope waves were reflected at the towers, at the end fixings and at the driving sheave. These could finally lead to stochastic overlays and thus to a high rate of transverse acceleration at local points of the line. The forces associated with this high acceleration were the probable cause of the derailment and subsequent crash of cabin 21.

3.2 Evaluation of brake test 5B (7:36 pm and 7:39 pm)

3.2.1 Brake tests 5B (5B.1 and 5B.2) were not indicated on the list of brake tests to be performed annually in Final O&M Manual NGONG PING 360, Part B) 4.7 – Service Brake, Chap. 5.9 Brake tests (annually), page 15 and 16 (see supplement 2).
This manual is said to have been handed out to Skyrail ITM and to EMSD by Leitner in June 2006.

3.2.2 Brake test 5B was dangerous.
This test was not performed during the commissioning of the Ngong Ping

Skyrail on 16. 5. 06. The danger could have been recognized by looking at the diagram of the brake test 5B.1 (diagram 4).

3.2.3 Brake test 5B had no recognizable technical necessity because of the following considerations:

- examination of the strength and/or efficiency (thermal capacity) of the brakes: one does not test that with empty cabins;
- examination of the correct function of the modulation of the brakes: are not tested by switching the modulation off. Incidentally, the preceding brake test No. 3 has already answered this question sufficiently;
- examination of the change of the traction resistance of the ropeway after the first year of operation: one needs a base for comparison. Brake test 5B.2 was not able to serve that goal, because it was not performed in 2006. (Conceivably for this could be a comparison of the coasting distances or the power reception, but not of a sharp braking);
- examination of the dynamic behaviour of the ropeway with strong deceleration: one would have to have instruments and observe the behaviour of the installation. (This was in fact not done. It would have been difficult to carry out in the oncoming darkness).

3.3 Was it at all intended to perform brake test 5B?

If one considers that brake tests 5B are not indicated in the list of brake tests, as shown in 3.2 above and that it was dangerous and without recognizable purpose, it is justified to ask, whether it was performed perhaps inadvertently in place of test 5. Brake tests 5 and 5B differ in that in brake test 5 the modulation is switched off in only one service brake group, while in brake test 5B the modulation units of both brake groups are switched off. In accordance with the verbal report of [redacted] of Leitner the term "uncontrolled " is used for the case with only one modulation unit switched off. Therefore when both groups of service brakes are unmodulated, this would be designated as "both groups uncontrolled ". This situation is neither intended nor desired. We did not find it in any manual supplied and not in writing anywhere.

3.4 The interplay of forces with sharp braking

3.4.1 The sensitivity of bicable uni-directional aerial ropeways to dynamic effects is an old and well-known fact. Such effects occur especially on braking. They typically cause cross-over of the hauling rope and lift empty vehicles off the carrying rope. The danger increases among other things with the operating speed, the length and slope of the spans and the rate of acceleration or deceleration. As early as 1951 Professor Czitary drew attention to this danger [1]. As far as we know accurate calculation methods exist only for monocable aerial ropeways [2] and reversible aerial ropeways [3]. The existing calculation methods for the dynamic behaviour of bicable gondolas [4, 5] are not applicable for our case. We estimate that one to two man-year work would be necessary to extend the existing methods to our application. In our case Leitner took account of the danger of lifting off by calculating the stability of the vehicles with ±50 % variation of the tension force in the hauling rope. In the case of Ngong Ping Skyrail this computation is in the Rope Calculation, Section II, Chapter 11: Proof of the lifting of the carriage (page 161-163, see supplement 6).

3.4.2 The most obvious danger during a sharp braking maneovre is that the increased hauling rope tension force will lift a(n) (empty) vehicle off the carrying rope. It is to be expected that in the case considered those vehicles are at most endangered, which are positioned after the exit from the braking station and/or on the highest point of the line. Vehicle 21 was, however, not far from the entrance to the braking station, where following a quasi-static view, a decrease of the tension force in the hauling rope was to be expected. (The reflection of the wave from the driving sheave might have been essential. How violent these longitudinal oscillations of the hauling rope were after the braking test 5B.2 in comparison with the preceding braking test (5B.1) shows the video of the monitoring camera at tower 4 and registration of the speed of the haul rope in the upper station)

3.4.3 A further dynamic effect is to be considered. If a vehicle is decelerated by the hauling rope, the cabin swings off in the driving direction because of its inertia. The carriage applies a momentarily increased normal force on the carrying rope. In the carrying rope a transverse wave is produced, which starts to run in both directions. The wave reaches the next tower and is reflected there. In our case the longitudinal speed of the wave in the carrying rope was about 200 m/s. The distance between the car and tower 2B was 173 m, i.e. the reflected wave reached the vehicle after approximately 1.7 s. During this time the vehicle implemented a half oscillation. Thus the reflection wave of the carrying rope met the vehicle in a swinging-off-position in the uphill direction (Fig. 2).

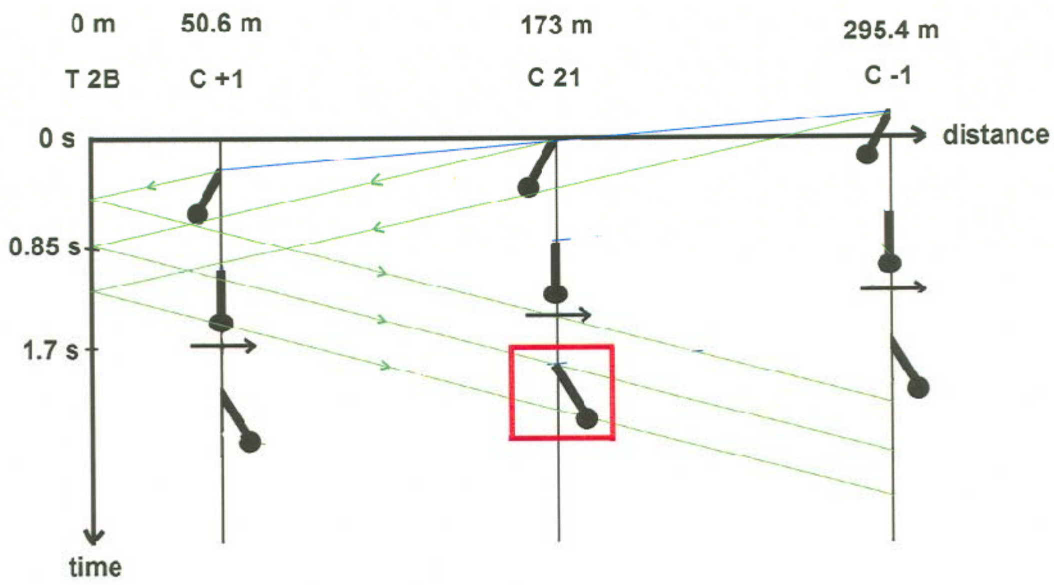


Fig. 2: The green lines show the run of the transverse waves of the carrying rope caused by the braking as described in the preceding text. The shift times for the vehicles C +1 and C -1 (blue line) are not based on computations, they show the qualitative influence only. The coincidence of the oscillation period of vehicle 21 and the running time of the wave reflected by tower 2B that meets it coincide; the reflected wave meets the vehicle at the moment, when it is in its furthest swing-off-position in the opposite direction (marked red).

Oscillation tests show that the oscillation period of the empty cabin is about 3.4 s. Therefore the cabin of vehicle 21 is in swing-off-position to the rear when the reflected wave meets the carriage. The wave has the tendency to lift off the carriage (Fig. 3). This could be the cause of derailment of cabin 21 and not any other vehicle. The lifting off must happen by lifting all four rollers simultaneously because according to tests derailment is not possible if only one half of the carriage is lifted off alternately.

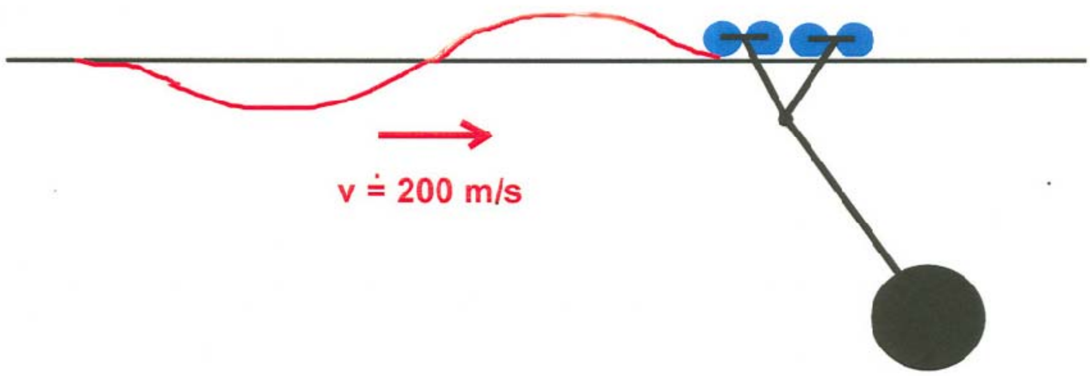


Fig. 3: If the transverse wave of the carrying rope running with approximately 200 m/s meets the carriage whilst the vehicle is in a swinging off position in the opposite direction it will tend to lift off the carriage (schematic sketch).

3.4.5 A third possible effect can take place when on sharp braking the increased friction (or blocking) in the bearing between carriage and suspension may lift the front and rear of the carriage of the swinging cabin alternately and so displace it from the carrying rope. This effect did not play any role here. The bearing of vehicle 21 under the load of the empty cabin showed on examination an insignificant bearing friction (the lower edge of the cabin stops at ±20 mm of deviation in case of the cabin moved forward and backwards with very slow back motion). On disassembling the bearing as shown in Fig. 4, it did not show any sign of rust; lubricant was present plentifully and in perfect condition.

Fig. 4: The suspension shaft was in perfect condition, more than sufficient lubricant was present.

3.4.6 The initial assumption that rope waves caused by the acceleration phase have an influence on the waves of the following braking proved as groundless. This became apparent during the measurements of dynamic behaviour at about the point of derailment (Fig. 5).

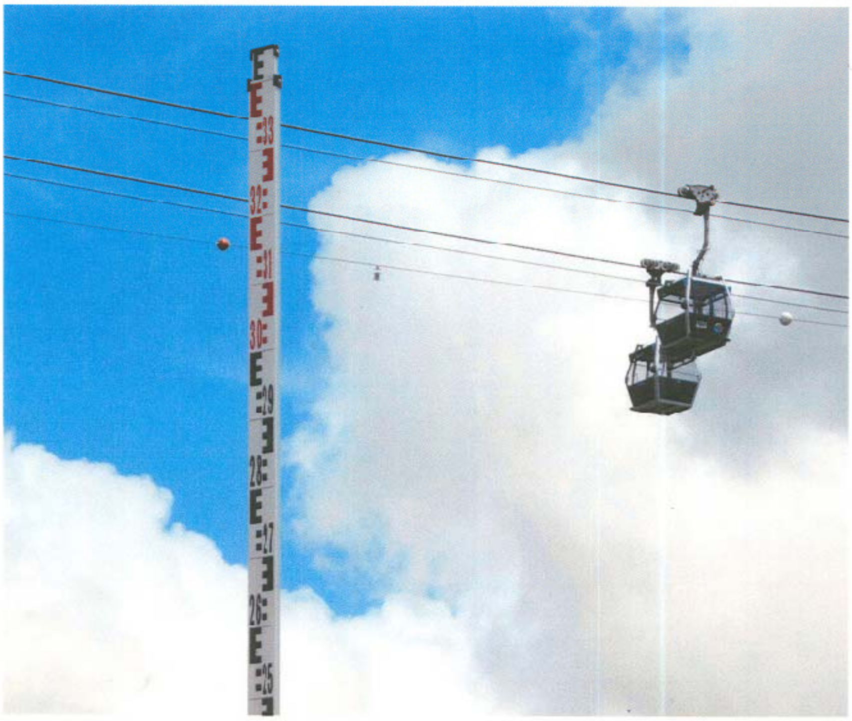


Fig. 5: Measuring assembly for the observation of the peak-to-peak swings that the ropes perform during acceleration and deceleration phases (conducted on 26. 6. 07)

3.4.7 To which extent the increasing tensioning force and the transverse waves of the hauling rope and that in the carrying rope caused the lift off of the carriage must finally be left open.

3.5 Other causes of derailing of cabin 21

There is no reason to suspect any cause for derailing of the carriage other than the sharp braking of brake test 5B.2.

- The tracks in the layer of lubricant on the carrying rope change in the range of the braking distance whereas it is constant before and behind that point. This shows that a sudden change took place in this range.
- On the carriage no deformations could be detected, that could have existed before the brake test 5B.2 and could have caused the carriage to get derailed.
- No wires exit the carrying rope that could have caused a derailing.
- A defect of tower 2B can be excluded, because the preceding vehicle passed it without problems and all the existing damage at tower 2B comes from vehicle 21 and/or from the derailed hauling rope.

4 Recomendations

Our recommendations are the following:

4.1 Concerning the staff and maintenance works:

4.1.1 Training of personnel should be improved and checked.

4.1.2 For all tests a clear operational sequence and responsibility plan should be provided.

4.1.3 All tests not contained in the O&M Manuals should be approved by the authorities and manufacturers.

4.1.4 It should be guaranteed that orders during operation, maintenance and tests are passed on clearly and safely, i.e. a clear discipline should exist during the transmission of questions and instructions. It should be guaranteed that orders are understood correctly by repeating the order by the receiver.

4.2 Concerning design

4.2.1 The dynamic behaviour of the ropeway should be reviewed with a view to improvement. In particular conditions should be noted under which significant oscillations arise.

4.2.2 Operating conditions should be examined for possible dangers, especially under deceleration. Further it should be determined which maximum possible rate of deceleration under such operating conditions should be allowed.

4.2.3 It should be guaranteed that partial derailing of a carriage stops the ropeway (e.g. by ground fault).

4.2.4 It should be assured that operations which must not be carried out at the same time are interlocked. (e.g. avoid the switching off of both modulation units of service brakes at the same time).

4.3 Concerning restart of installation:

4.3.1 All checks that are to be conducted after one year of operation should be carried out.

4.3.2 All parts of the installation that might have been damaged by the incident should be checked (especially all vehicles, towers and ropes).

4.3.3 As long as requirement 4.2.2 is not fulfilled the speed should not exceed 5,0 m/s.

4.3.4 The requirement 4.2.4 should be fulfilled before restart of installation. It is strongly recommended to fulfil requirement 4.2.3 before restart of installation, too.

4.4 Concerning the manuals:

4.4.1 It should be clarified which version of documents (e. g. T&C Report, O&M Manuals) is valid.

4.4.2 Concerning the manuals one single term should be used for the same item.

4.4.3 The term "unmodulated" or "uncontrolled" is misleading. It is not defined whether the switching off of the modulation unit of one or both groups of service brakes is understood. It should be checked whether still other misleading definitions exist. All misleading definitions should be clarified.

4.5 Additionally we recommend:

4.5.1 EMSD should participate in ITTAB meetings (Internationale Tagung der Technischen Aufsichts-Behörden = International Meeting of Supervisory Authorities of Ropeways) to get acquainted with colleagues and improve practical knowledge concerning ropeway operation and incidents.

4.5.2 The recommendations contained in "Ngong Ping 360 Incident Report" of Skyrail ITM should be examined for their relevance.

Bibliography:

[1] E. Czitary: Seilschwebebahnen. Page189
Springer Verlag Wien, 1951

[2] Th. Richter: Schwingungsverhalten von Einseil-Umlaufbahnen beim Anfahren und Bremsen
ETH Zürich, Institut für Leichtbau und Seilbahntechnik, 1989

[3] G. Kovàcs: Schwingungsverhalten eines Pendelbahnfahrzeuges bei einseitigem Zugseilriss und anschliessender Tragseilbremsung.
ETH Zürich Institut für Leichtbau und Seilbahntechnik, 1994

[4] R. Beha: Bewegungsverhalten und Kraftwirkungen des Zugseiles und der Fahrzeuge von Zweiseilbahnen zur Berechnung der Zugseilbahnen zur Berechnung der Dynamik des Gesamtsystems.
Universität Stuttgart, 1994

[5] S. Liedl: Bewegungen und Kräfte des Seilsystems und der Fahrzeuge von Seilschwebebahen im Fahrbetrieb.
Dissertation TU München, Lehrstuhl für Fördertechnik, Materialfluss, Logistik, 1999

Zürich, Wien, 29. 7. 2007

(Prof. Dr. Gabor Oplatka) (Prof. Dr. Josef Nejez)

Enclosed: 8 supplements

Supplement 1

Mechanical Test & Commissioning (T&C) Report

Braking Tests – Operating Conditions (page 72)

Attachment 5.1.2.1 with 4 diagrams

5. BRAKING TESTS

5.1. Braking Tests - Operating Conditions

Description of Works:

Braking tests shall demonstrate, that the cable car can be stopped safely within reasonable time under any load condition.

Braking tests are normally carried out repeatedly, very often with the same load condition as before. If no special precautions would be taken, the carriers would always enter the terminals / stations during braking, which would every time slightly change the carrier distance without having the chance to restore, this would further lead to problems with the safety devices. Additionally it would cause an unnecessary wear of the equipment.

In order to reduce effect from this situation (due to the many stations it is impossible to avoid it totally), loads of a certain no. of cabins is distributed in a lower no. of cabins (means overload in certain cabins), in order to avoid full loaded carriers to enter terminals / stations.

The following tests have to be carried out:

- Auto deceleration
- Normal braking with motor, normal deceleration rate
- Normal braking with motor, high deceleration rate
- Braking with modulated service brake, normal deceleration rate
- Braking with modulated service brake, high deceleration rate
- Braking with service brake but not modulated (e.g. battery is failing)
- Braking with modulated emergency brake, normal deceleration rate
- Braking with modulated emergency brake, high deceleration rate
- Braking with emergency brake but not modulated
- Braking with emergency brake using the manual lever
- Braking caused by over speed
- Braking caused by reverse direction

Location: N/A

Load Conditions:

The tests have to be carried out with the shortest (122.4 m) and longest carrier distance (238.7 m) with most unfavourable load in both uphill and downhill direction. The shortest carrier distance (**122.4 m**) is driven in section II by **2 gear units and 4 motors** while the longest carrier distance (**238.7 m**) is driven in section II by **1 gear unit and 2 motors** only, when only 13 passengers enter the cabin. Due to the rising and descending sections between TCT and NPT, the highest load occurs with a special load distribution.

Tung Chung Cable Car Project
Contract No. 5200 - Aerial Ropeway
Mechanical Part of Test & Commissioning - Record Sheets

LEITNER® ropeways

Attachment 5.1.2.1: Braking Tests Operating Conditions - 122.4 m - Empty Carriers

Name of Inspector: [redacted]

Date: 16 May 2006

Signature of Inspector: [redacted]

Witnessed by: [redacted]

Test power supply shut off ↳ braking with controlled service brake	Torque I / II [%]	Travel Distance [m]	Speed [m/s]	Braking Time [s]	Deceleration [m/s²]	Findings	
Electrical braking by **motor** with **"Stop"**	23/40	58.7/60.1	7.0	16.4/16.7	0.41/0.40	-15% } during -67% } stop	①
Electrical braking by **motor** with **"Fast Stop"**	24/29	38.7/39.6	7.0	11.0/11.1	0.61/0.60	-34% } during -123% } stop	②
Mechanical braking by **service brake, controlled, normal** deceleration	24/42	59.9/59.6	7.0	17.3/17.2	0.40	→ change parameters	→ ⊗
Mechanical braking by **service brake, controlled, fast** deceleration	22/35	32.7/32.2	7.0	9.3/8.7	0.73/0.74	✓	④
Mechanical braking by **service brake, uncontrolled, normal** deceleration	22/39	20.3/23.7	7.0	5.9/8.7	1.18/0.80	✓	⑤
Mechanical braking by **service brake, uncontrolled, fast** deceleration			n.a.				
Mechanical braking by **emergency brake, controlled,** normal deceleration	26/41	25.3/60.1	7.0	7.3/17.3	0.94/0.40	emergency + service brake applied	⑥
Mechanical braking by **emergency brake, controlled,** fast deceleration							
Mechanical braking by **emergency brake, uncontrolled**				n.a.			
Mechanical braking by **emergency brake, manual valve**							
Auto-Acceleration / Deceleration							
Electrical overspeed %			separate	test			
Mechanical overspeed with pendulum %		see					
Service brake controlled normal deceleration	13/[illegible]47	62.2/57.6	7.2/7.0	16.6/16.2	0.39/0.42	with different control parameters	→ ⊗
Emergency brake controlled	11/45	26.5/61.9	7.0	7.5/17.4	0.94/0.39	without service brake	
Service brake controlled normal deceleration	22/52	53.6/59.2	7.0	16.4/16.6	0.40/0.41	with different control parameters	→ ⊗
— " —	15/46	57.6/58.7	7.0	16.1/16.4	0.42/0.41	final parameters	③

Diagram brake test Nr. 1:

Diagram brake test Nr. 2:

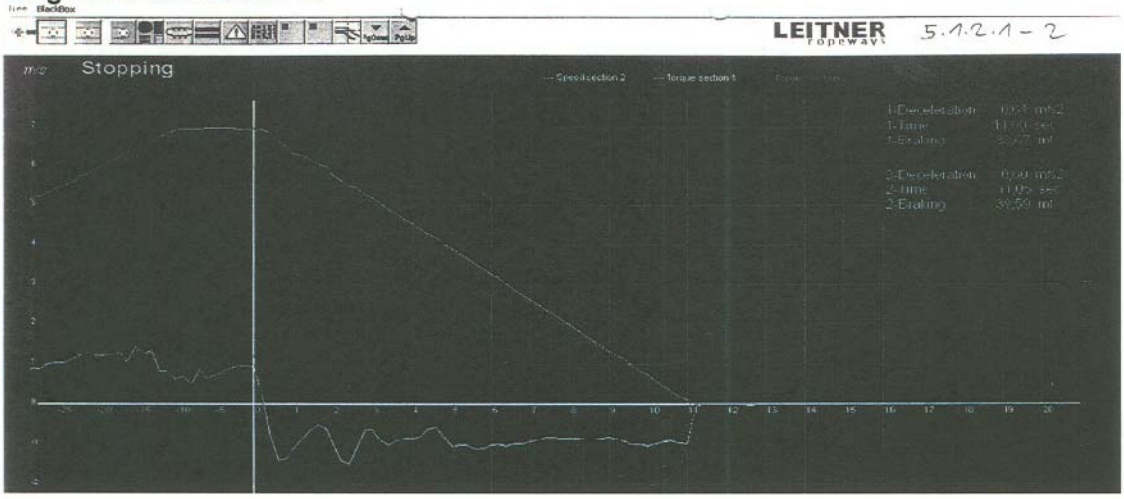


Diagram brake test Nr. 3:

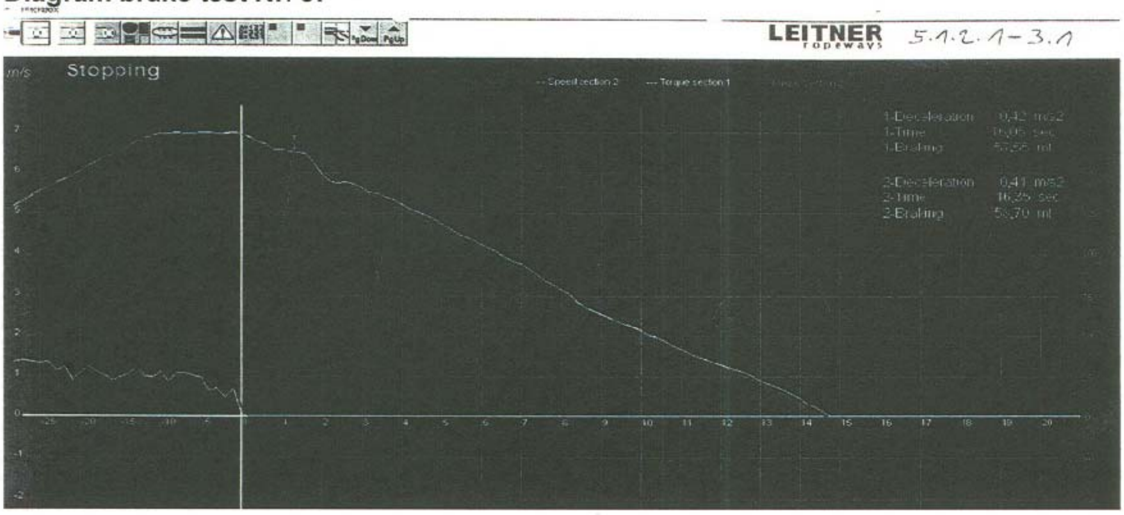


Diagram brake test Nr. 4:

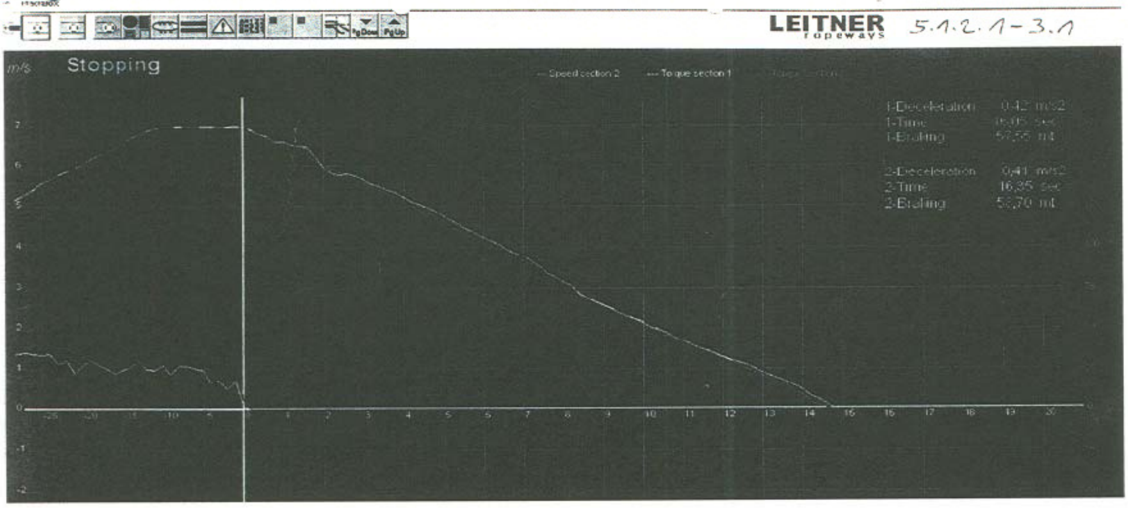


Diagram brake test Nr. 5:

Supplement 2

Final Operating & Maintenance (O&M) Manual

Part: B) 4.7 – Service Brake

Chapter 5.9 Brake tests (annually) (page 15 and 16)

5.7 Inspection of surface coating (6 months)

Careful and detailed cleaning is required in order to prevent corrosion and should therefore be carried out regularly in case of soiling.

The surface of the elements has to be inspected for the formation of rust. If required, the protective coating has to be repaired professionally.

Corroded and damaged small parts such as bolts, washers, nuts, split-pins, etc. have to be replaced.

5.8 Lubrication of spring (3,000 hours / annually)

Lubricate spring. Type of grease: see Component Manual "B) 0.5: Table of Lubricants".

5.9 Brake tests (annually)

Annual brake tests have to be carried out with

- shortest carrier distance (122.4 m / 100% transport capacity / 109 cabins on line)
- travelling speed 7 m/s

with the following load conditions:

- all cabins empty
- max. load downwards with load of 17 passengers (17x75 kg) per cabin

Reference is made to the braking tests which have to be done with the emergency brake using partly the same load conditions, those tests shall be done at the same time as the tests of the service brake. Please refer to Component Manual "B) 4.8: Emergency Brake - Mechanical Part".

5.9.1 Empty cabins

As the service brakes are normally controlled and provide a constant deceleration rate independently from the load condition (except in the range of maximum load), it is difficult for the personnel to realize any difference in brake efficiency.

In order to have the possibility to check the efficiency for any changes, instead of the deceleration rate the current of the electromagnets of the service brakes is used for evaluation.

All cabins have to be empty for the test. Start the cable car and operate with travelling speed 7 m/s. The brake test can start any time, push the red "Stop Service Brake" button in the control room of AIAS.

The service brake is acceptable, when both sections of the cable car can be stopped after a travel distance of about 60 m and a deceleration rate of about 0.4 (+/-0.02) m/s^2, the brakes were held more or less open during braking (refer to the current of the electromagnets) and the emergency brake was not applied to maintain the deceleration rate.

The diagrams showing the current of the electromagnets of the brakes section II, both for service brake 3+4+7+8 and 5+6+9+10, have to be saved on the computer, printed and compared with the diagram of the respective test during T&C, refer to the As-Built Document "C) 1.5: Test & Commissioning (T&C) Report", part "Mechanical Test & Commissioning (T&C) Report ", clause 5.1.2.1, diagrams 5.1.2.1-3.2 and -3.3, or refer to Figure 6 and 7.

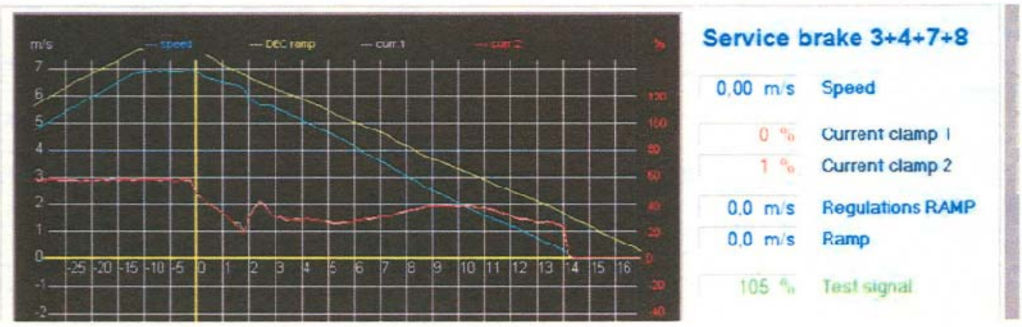


Figure 6: Diagram current of the electromagnets service brake 3+4+7+8 "Service brake controlled, normal deceleration" of T&C

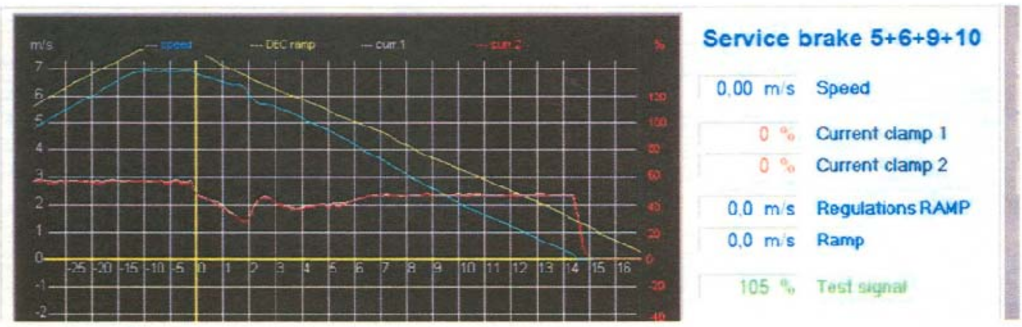


Figure 7: Diagram current of the electromagnets service brake 5+6+9+10 "Service brake controlled, normal deceleration" of T&C

WARNING!

- **If the current of the electromagnets or the brake data deviate significantly from those of the tests during T&C, contact the LEITNER company for clarification!**

Supplement 3

Witness Statement of [redacted]

Including: Brake test and preliminary statement

Supplement 4

Witness Statement of [redacted]

Supplement 5

Witness Statement of [redacted]

Supplement 6

Rope Calculation

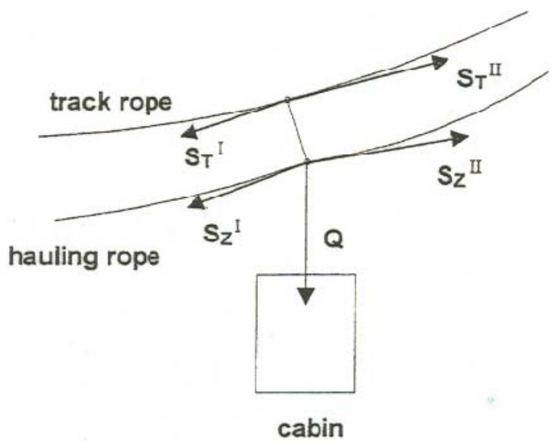
Section II, Chapter 11 (page 161-163)

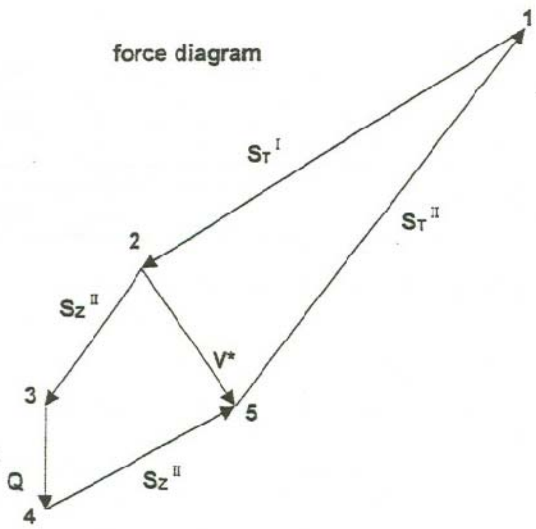
Proof of lifting off of the carriage

11. PROOF OF LIFTING OFF OF THE CARRIAGE

According to CoP it has to be proven that the carriage is not lifted off in case of increase or reduction of the hauling rope tension force by 50 %.

In a bicable ropeway the track rope has a carrying function, the hauling rope the hauling function. As far as the forces acting onto the carrier are concerned, the rope tension forces of track rope and hauling rope as well as the acting load Q have to be balanced.





According to chapter 6.6 the increase of the rope tension force of the track rope due to the carriers travelling along the different rope spans was calculated assuming an evenly distributed load. If the hauling rope tension force is increased, the hauling rope progressively takes over the carrying function from the track rope.

The decisive load case for the lifting off of the carriage is the load case with empty carriers at the distance between carriers A_{MAX} and the minimum temperature T_{MAX} since this load case has the lowest increase of track rope tension force.

In analogy to chapter 6.6 the increase of the track rope tension force due to the carriers travelling along the individual rope spans is calculated with increased or reduced hauling rope tension force. Since the lowest increase of track rope tension force results for this load case in section 3 between the Angle station and Ngong Ping Terminal and the hauling rope tension force is also great in the area of the Angle station, therefore this examination is only carried out for section 3.

11.1. *50 % increase of hauling rope tension force*

Hauling rope tension forces

Empty carriers

span	f_{mi}	S_{HH} at span centre	S_{HH} total	S_{HW} at span centre	S_{Hm} at span centre	H_H
	[m]	[kN]	[kN]	[kN]	[kN]	[kN]
9	0.91	0.4	0.7	0.2	406.0	405.3
10	34.10	-1.2	-7.1	-2.4	398.2	396.0
11	5.49	-1.0	-2.7	-0.9	391.9	389.9

Track rope tension forces

Empty carriers

span	ΔS_{Ti}	S_{Ti1}	S_{Ti2}	f_{mi}	φ_{Ti1}	φ_{Ti2}
	[kN]	[kN]	[kN]	[m]	[°]	[°]
9	8.0	995.0	997.6	0.91	2.02	4.60
10	8.0	997.6	969.3	34.10	-13.83	2.03
11	8.0	969.3	958.5	5.49	-8.97	-2.53

In spite of the 50 % increase of the hauling rope tension force the carriages of the carriers will still be supported on the track rope due to the still increased track rope tension force ΔS_{TL}, as required in the CoP.

11.2. *50 % reduction of hauling rope tension force*

Hauling rope tension forces

Empty carriers

span	f_{mi}	S_{HH} at span centre	S_{HH} total	S_{HW} at span centre	S_{Hmi} at span centre	H_H
	[m]	[kN]	[kN]	[kN]	[kN]	[kN]
9	0.98	0.4	0.7	0.2	146.0	145.7
10	36.52	-1.0	-7.1	-2.4	138.0	137.3
11	6.09	-1.0	-2.7	-0.9	131.9	131.2

Track rope tension forces

Empty carriers

span	ΔS_{Ti}	S_{Ti1}	S_{Ti2}	f_{mi}	φ_{Ti1}	φ_{Ti2}
	[kN]	[kN]	[kN]	[m]	[°]	[°]
9	177.0	1164.0	1166.6	0.98	1.92	4.70
10	177.0	1166.6	1138.3	36.52	-14.36	2.61
11	177.0	1138.3	1127.5	6.09	-9.19	-2.29

In case of a 50% reduction of hauling rope tension force the increase of the track rope tension force ΔS_{Ti} is increased due to the carriers travelling along the rope spans (see chapter 6.6.6.3), because due to the low hauling rope tension force the sag of the hauling rope between the different carriers is still greater.

Supplement 7

Relevant Regulations:
Extract: Switzerland, Bicable uni-directionl ropeways 1986 (2001)

Relevant Regulations:

(1) Switzerland, Bicable uni-directional ropeways 1986 (2001):

444 Lifting of the carriage

1. The carriages of empty vehicles on bicable uni-directional aerial ropeways must not lift off the carrying rope under the following conditions:

1.1 the highest tension in the hauling rope is raised by 40% from the highest value under monotonous movement

1.2 dynamic forces (paragraph 412.3) act on the ropeway

412.3 Under the worst case combination of the load on the ropeway and the largest brake force of the service brake (residual pressure equals zero or the loss of braking control) the following operating conditions apply:

.3.1 passengers must not be lifted from their seats

.3.2 vehicle must not touch the ground or the snow

.3.3 neither the carrying rope nor the hauling rope must be lifted from their rollers (........)

(2) CEN Ropeway Standards of Technical Committee TC 242:

Safety requirements for cableway installations designed to carry persons (relevant requirements not in details here)

Supplement 8

List of some dynamic incidents that led to crash of a vehicle

List of some dynamic incidents that led the crash of a vehicle.

(Note: For Bicable uni-directional ropeways except the third incident and this list has no claim to be completed)

1971 Spain: Passengers swing the vehicle. The oscillating vehicle is caught on the tower and crashes.

1969 Germany: An installation with a Ward-Leonard drive is suddenly accelerated from 1.3 m/s to 2.8 m/s. The cabin hits the carriage. The carriage is partially derailed, catches on the crest frame and crashes.

(1987 Italy): The brakes were applied too fast (over braking) on a single rope unidirectional aerial ropeway. Five cabins each with a capacity of 6 persons crash. All brakes acted in an uncontrolled mode. Four of the five cabins were empty.

1997 Austria: After 22 years of operation without any such problems an empty cabin is lifted off the carrying rope just as it leaves the upper station in normal operation. The reason it is lifted off is the high tension in the hauling rope. The cabin is caught on the next tower and crashes. A similar accident takes place at the same point six months later on the occasion of a brake test.

附件三

Nejez 教授對昂坪纜車設計、操作、保養及管理的意見

2nd Input to Report of Expert Panel

Ngong Ping Skyrail 360
Technical Problems

Author:

Prof. Dr. Josef Nejez

2nd Input to Report of Expert Panel

Ngong Ping Skyrail 360
Technical Problems

Requested by:

Electrical and Mechanical Services Department (EMSD)
Government of the Hong Kong Special Administration Region
3 Kai Shing Street, Kowloon, Hong Kong

Provided by:

Univ.-Prof. Dipl.-Ing. Dr. techn. Josef Nejez
General court-appointed expert for the field of ropeways
Bruckhaufner Hauptstrasse 15
1210 Wien
AUSTRIA

Date of report: 22nd of July 2007
Number of pages: 6

1. Introduction

During my stay in Hong Kong in connection with the investigation of the incident of 11 June 2007 I was asked by EMSD to have a look at the ropeway and point out further technical problems, which may impair the availability and/or safety of the installation in the future. As agreed upon there was undertaken a random survey throughout the installation only. This survey is not to be considered as an investigation.

2. Findings

During the survey no defects were determined, which could at present represent a danger for the ropeway. Problems, which may impair the availability and/or safety of the installation in the future or at least affect the appearance of the ropeway, are the following:

2.1 In the course of the survey it turned out that many construction units show indications of rust, which one does not expect with a so recent installation. Figures 1 to 11 show such construction units.

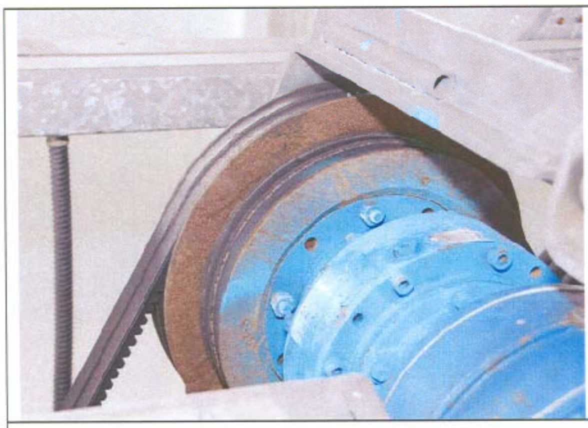


Fig. 1: Rusty V-belt pulleys at the driving motor of the conveyer systems

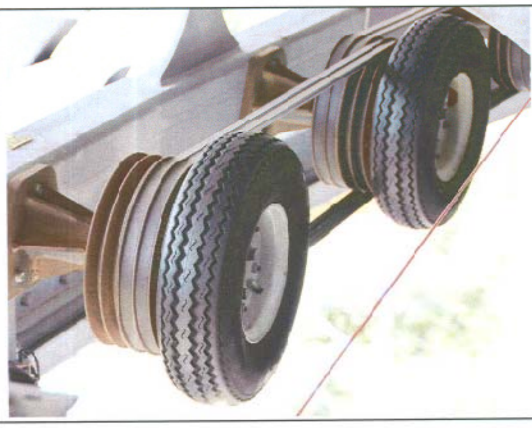


Fig. 2: Rusty V-belt pulleys at the conveyer systems

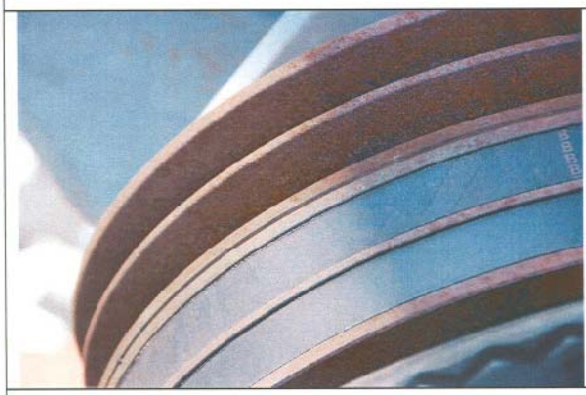


Fig. 3: Rusty V-belt pulleys at the tconveyer systems (detail)

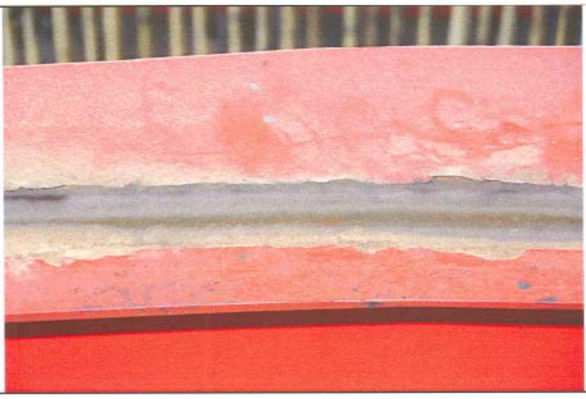


Fig. 4: Rust and peeling coat of paint at the coupling rails

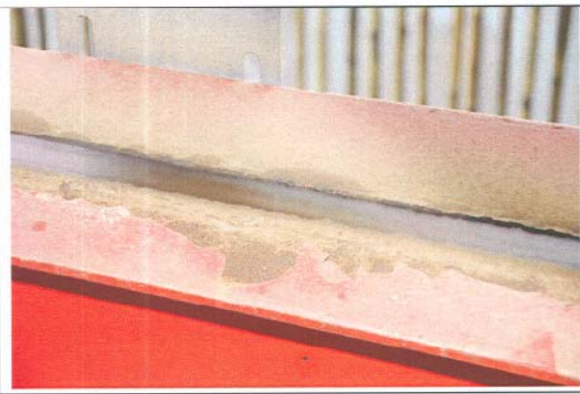


Fig. 5: likewise

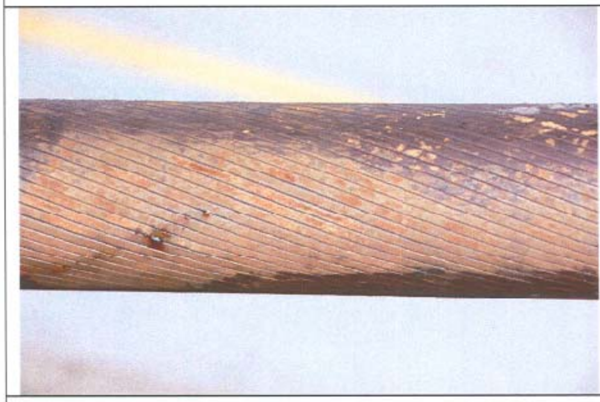


Fig. 6: Rust at the carrying rope within the range of Nei Lak Shan Angle Station

Fig. 7: likewise

Fig. 8: likewise

Fig. 9: likewise

Fig. 10: Rusty axles of the connection of suspension and cabin

Fig. 11: Even the new axles of the connection of suspension and cabin show traces of rust.

2.2 Within the range underneath the mobile platform in Tung Chung Terminal and Ngong Ping Terminal water was found, which can damage the drive of the mobile platform (electrical and mechanical parts under water). Figures 12 and 13 show that range underneath the platforms.

Fig. 12: Water within the range underneath the movable platform in Tung Chung Terminal

Fig. 13: Water within the range underneath the movable platform in Ngong Ping Terminal

2.3 On some anchor drums the outer layer of z-wires of the carrying rope show structural problems (e. g. Fig. 14 and 15). As Prof. Oplatka has told me Fatzer (manufacturer of the ropes) already took care of the problem.

Fig. 14: Structural problems of the carrying ropes in the outer layer of z-wires

Fig. 15: likewise

2.4 During the visit of the ropeway it turned out, that vehicle loading and unloading of the line takes a long time because of fault stops because of spatial displacements of cabins. It was said that because of this reason the cabins usually stay on the line during the nighttime and are not stored up in the garage in Tung Chung Terminal. This causes unnecessary stress of the vehicles and the ropes.

3. Recommendations

3.1 Rust protection should be generally improved.

3.2 The range underneath the mobile platforms in Tung Chung Terminal and Ngong Ping Terminal should be drained.

3.3 It should be clarified weather the structural problems of the carrying ropes on some of the anchor drums may cause problems in the future (e. g. at the time of relocation of the carrying ropes).

3.4 Loading and unloading procedure of the ropeway should be improved. The vehicles should usually be stored up in the garage at Tung Chung Terminal during the nighttime.

Vienna, 22nd of July 2007

J. Nejez
....
(Prof. Dr. Josef Nejez)

附件四

機電工程署就昂坪纜車
發表的
表現檢討

PERFORMANCE REVIEW OF NGONG PING 360 CABLE CAR SYSTEM

Purpose

This paper reviews the performance, reliability and underlying causes of major incidents of Ngong Ping 360 (NP360) cable car system since its opening on 18 September 2006, outlines the associated findings and recommends way forward to enhance system reliability and to regain public confidence.

Background

2. There were all together 11 major incidents since the opening of NP360 for public use since 18 September 2006. These incidents have drawn intense public and media attention on the reliability of the cable car system.

The incidents

3. Among the 11 incidents, 3 were due to poor weather condition, 1 was due to inappropriate operation and maintenance and 7 were due to equipment/part failure. A summary of these incidents is given in **Annex 1**.

4. In response to these incidents, we have advised and Skyrail (the operator of NP360) has taken remedial and improvement measures including enhancement of operation and maintenance procedures, increase in manpower, better equipped with tools and spares, addition of monitoring devices and fine-tuning of the cable car system.

Areas of Concern

5. EMSD has closely monitored the progress of the remedial and improvement measures, as well as performance of the system. These measures aim to enhance system reliability and shorten the recovery time should system stoppage occur. However, it appears that some of the equipment/part failures were related to the quality of the equipment of which routine maintenance may not be able to prevent. For example, moisture was found inside the defective speed encoder that caused the stoppage incident on 3 January 2007.

6. In addition to the findings given by Skyrail in their investigation reports, our own incident investigation and on-site monitoring inspection revealed various problems in the system. For example, some of the metallic parts start getting rusty under the misty environment in North Lantau area. As these parts should have been designed to withstand local operation environment, the observed rate of deterioration and the high failure rate of components have nonetheless arouse concern.

7. Deriving from our on-site observations, a number of areas where improvement measures are required were made clear to Skyrail. A summary of the improvement measures recommended in the past and their associated progress is given in **Annex 2**. The information given in Annexes 1 and 2 indicate inadequacies in various areas and the possibility of recurrence of stoppage incident is likely. Furthermore, timely and systematic fault diagnosis is essential to efficient and speedy service recovery. However, the diagnostic software and procedure provided by the cable car manufacturer have apparently rooms for improvement. In view of the aforesaid, there is a need to review the design standard and quality of these equipment/parts with a view to enhancing overall system performance.

Recommendations

8. We are of the view that the design standard and quality of equipment, as well as the effectiveness of the diagnostic software and procedures have contributed to the repeated occurrence of incidents during the past months.

9. We recommend that an independent review of the cable car system should be conducted with regard to the following aspects :-

(a) design standard, quality and reliability of major equipment/parts and the cable car system as a whole;

(b) the current operation and maintenance management including fault prevention, recording, diagnosis and recovery procedure;

(c) performance benchmarking with overseas cable car system of similar design; and

(d) improvement measures for minimizing service interruption and thus enhancing system reliability.

10. In view of the potential risk of repeated equipment failure and hence system stoppage, we recommend the review to be completed within four weeks.

11. As MTRCL is the ultimate owner of the cable car system, it is recommended that MTRCL to engage an independent party to conduct the above-mentioned review as soon as possible.

Electrical and Mechanical Services Department
12 January 2007

Annex 1

Summary of major incidents occurred since the soft opening of NP360 for public use from 18/9/2006

Date	Impact	Stoppage Time	Cause	Underlying Problem
Sep 23, 2006	Stop boarding of passenger	10:00 – 10:15 (15 min) stop boarding of passenger, no stoppage of system	Strong wind	-
Sep 24, 2006	Stop boarding of passenger	13:24 – 13:56 (32 min) stop boarding of passenger, no stoppage of system	Strong wind	-
Sep 30, 2006	Stop boarding of passenger	9:00 – 9:39 (39 min) stop boarding of passenger, no stoppage of system	Strong wind	-
	Suspension of Service	10:35 – 11:26 (51 min) stop boarding of passenger; 10:35 – 11:13 (38 min) stoppage of system	Equipment failure (defective plug)	Operation blunder (poor engineering change management)
Oct 8, 2006	Suspension of Service	16:48 – 17:46 (58 min) stop boarding of passenger; 16:48 – 17:21 (33 min) stoppage of system	Equipment failure (insufficient clearance for haul rope)	Design imperfection
Oct 15, 2006	Service could not be started on schedule	10:00 – 11:06 (66 min) no service	Delay in maintenance work causing system not ready for operation on time	Poor operation and maintenance coordination
	Intermittent Stoppage	18:05 – 19:00 (55 min) intermittent stoppage	Equipment failure (poor contact of cable connector)	Poor design standard/ quality of component
Oct 27, 2006	Service could not be started on schedule	10:00 – 14:20 (4 hr 20 min) no service	Equipment failure (defective component on conveying system in Cabin Storage Area)	Design imperfection/ workmanship imperfection/ inappropriate torque limit setting
Nov 28, 2006	Suspension of Service	12:22 – 12:45 (23 min) stoppage of system	Equipment failure (friction belt not enough tension)	Poor maintenance strategy

Date	Impact	Stoppage Time	Cause	Reflected Problem
Jan 1, 2007	Intermittent Stoppage	16:14 – 17:26 (1 hr 12 min) stop boarding of passenger 16:29 – 16:35 (6 min) stoppage of system	Equipment failure (Air leakage on friction tire)	Poor quality of inner tube of tire and poor maintenance strategy (repeated tire failure)
Jan 3, 2007	Suspension of Service	18:20 – 19:38 (1 hr 18 min) stoppage of system	Equipment failure (Defective speed encoder)	Poor design standard/ quality of component

Annex 2

Summary of improvement items recommended and the associated progress

Date	Observation	Measures Recommended	Underlying Problem	Progress
July 31, 2006	Maintenance technician worked alone to attend fault	Strengthening of on-site supervision of maintenance activities	Poor maintenance system	Completed with satisfactory results
Aug 2, 2006	Dislocation of outer wires at the terminals of track ropes was observed	Monitoring of the condition of wire dislocation on track ropes at terminals	Inadequate awareness	On-going with close monitoring the condition via maintenance
Sep 17, 2006	Recurrence of stoppage due to "Cabin door not closed/locked" appeared	Replacement of original actuator for cabin door lock by stainless steel actuator	Poor design standard and quality of component	Completed with satisfactory results
Oct 10, 2006	The last motor speed encoder was used	Ordering of spare motor speed encoder	Poor stock management	Completed with satisfactory result
Oct 15, 2006	Proximity switch was found not function properly	Use of connector with better design standard and quality on sensors	Poor design standard and quality of component	Trial in progress
Oct 15, 2006	Recurrence of intermittent stoppage due to the activation of "Collision of Vehicle" alarm	Enhancement of operation procedures and improvement of software for controlling anti-collision alarm	Operation imperfection	Completed and performance being closely monitored
Oct 16, 2006	The last cabin with passenger was not properly reported	Reminding all controller and operators to follow the proper arrangement of "Reporting Last Cabin"	Poor operation	Completed with satisfactory result
Nov 3, 2006	A large amount of pulleys in synchronization system were found rusty after opening for use for a short period of time	Replacement of rusty pulleys	Poor design standard and quality of component	Replacement work in progress

Date	Observation	Measures Recommended	Underlying Problem	Progress
Nov 3, 2006	Excessive wear of belts and pulleys was found after opening for use for a short period of time	Study causes of excessive wear of belts and pulleys and strengthen maintenance	Poor design standard and quality of component	Study in progress while maintenance has been strengthened
Nov 3, 2006	Elongated tension belt with good condition needs replacement	Addition of tensioning device for tension belts in synchronization system	Poor design	Trial in progress
Nov 16, 2006	Malfunction of the anemometer at Tower 4 was encountered	Restoring the proper functioning of anemometer at Tower 4 due to connection problem	Poor design standard and quality of connection	Completed with satisfactory result
Jan 5, 2007	One of the three bolts for engaging/ disengaging rescue drive was found broken but was not reported/recorded	a) Replacement of bolt for engaging/ disengaging rescue drive	Poor maintenance management	Completed with satisfactory result
		b) Developing appropriate tools/gauge for checking the movement of engaging/ disengaging rescue drive	Poor maintenance system	Improvement work in progress
		c) Enhancing fault recording, reporting, tracking and analysis system	Poor maintenance system	Improvement work in progress

<u>附件五</u>

TÜV SÜD 就昂坪纜車

發表的

獨立系統檢討

Hong Kong

Choose certainty.
Add value.

Report

on the independent system review of
NP360 Cable Car System

Hong Kong , 30 May 2007

HK-IS /SF

Report ISR NP360 30-05-2007.doc

Date: 2007-05-30

Report no: **936 266**

Subject: Bi-cable Aerial Ropeway
Ngong Ping 360
HONG KONG

Manufacturer: Leitner GmbH

Customer: MTR Corporation Limited
MTR Tower
Telford Plaza
33 Wai Yip Street
Kowloon Bay
HONG KONG

[redacted]
Account No [redacted]
SWIFT Code [redacted]

General Manager:
Hugues Vincendeau (CEO)

Telephone: +852 2776 1323
Telefax: +852 2776 1372
www.tuv-sud.hk

TÜV SÜD Hong Kong Limited
Unit 601, InnoCentre
72 Tat Chee Avenue
Kowloon Tong
Hong Kong

Contents

Hong Kong

1 Introduction

At the request of MTRCL TÜV SÜD undertook an independent system review of the Ngong Ping 360 bi-cable ropeway system. The purpose of the independent system review was to provide an independent expert opinion on the performance and the reliability of the ropeway system.

The independent system review covers aspects of operation, maintenance, components and systems of the ropeway. In addition the incidents that have occurred since opening of the cableway and the corrective actions taken were assessed for appropriateness.
TÜV SÜD reviewed the operation and maintenance procedures and verified their implementation on site.

2 Findings

Based on TÜV SÜD's experiences as an authorized inspection body, the reliability of the Ngong Ping cableway during its initial operating period is considered to be in line with the best practice of comparable systems. In comparison to more than 100 ropeways for which TÜV SÜD regularly carries out approvals and annual inspections, we consider the overall operational performance of Ngong Ping 360 ropeway to be high.

The cable car system and the components are essentially suitable in terms of robustness and maintainability.

Based on our inspection on site we consider that the ropeway system and the current method of operation present no more of an operational risk than that of similar installations. The safety performance is at the same high level as similar installations and no items were found that would restrict the safe operation of the system.

NP 360 has been designed for a rope speed of 7 m/s. The examination and inspection of the cableway system by the ropeway surveyor was conducted and approved with the designed rope speed of 7 m/s prior to public operation. In completing the independent system review we found no reason that would prevent increasing the current operating speed from 5m/s to 6 or 7m/s assuming all conditions, such as wind speed, are within the limits set by the design and the related standards. Although there was no requirement for approval tests and trial operations for full speed within the scope of our review, e.g. braking tests under full load condition and evaluation of the dynamic behaviour of the ropeway under these conditions we believe it to be appropriate to incrementally increase the operating speed to allow the operating staff to get used to the increased speed.

The proposed additional weather protection device of a rain screen at Nei Lak Shan Station will protect the cableway components from direct rain but not from moisture arising from humid environmental conditions. Thus if a rain screen is installed, enhanced maintenance and improving susceptible components will still be necessary as moisture can still penetrate the station area.
As such the benefit of a partial improvement should be weighed against the investment cost.

During our inspection no major deficiencies were identified. There are however a number of minor issues that could, cumulatively impose a risk of unnecessary interruptions to public operation. These issues could benefit from improvement and although no single one would produce a step change in overall reliability together they would provide an opportunity for continuous improvement to the system over the medium to long term.

The proposed solutions and the corrective actions taken rising from the incidents that have occurred since opening to the public are considered to be appropriate.

3 Operational Review

The operational procedures are considered to be generally complete although some of these require some additional input, e.g.

- Whenever it is considered safe to bypass safety functions, substitute measures should be clearly defined which would permit the continuing operation of the cableway system by authorized operating staff under safe conditions.
- Some areas of the operation and maintenance (O&M) manual require additional detail to allow the operator to improve the procedures.
- Additional structure should be provided to the existing organizational arrangements to more clearly define the roles, responsibilities and authorisation of the operating staff.
- The Ongoing training for all operation staff should be continued to maintain and provide continuous improvement to staff.

4 Maintenance Review

The maintenance procedures are considered to be a little less developed than the operational procedures. Some of the existing procedures require additional details and input and new procedures for the maintenance activities should be established, e.g.

- Checklists should include all relevant tests and be referenced to the O&M manuals.
- More extensive checks should be undertaken to the carrier components on a daily basis.
- The procedures for disassembling components should include detailed information as necessary to allow the correct tools, materials and spares to be used, ensuring reconditioned components are suitable for operational use.
- Ongoing training for the maintenance team should continue. Specialisation of all technicians by discipline is recommended with individual skill sets detailed in a capability and competence matrix.

5 Review of Cableway System / Components

The installed cable car system generally was found to be in good condition. However, the level of corrosion in some areas arising from adverse environmental conditions was found to be higher than anticipated. Improvements and corrective actions for the enhanced protection of system components against corrosion have commenced and are being undertaken in an appropriate manner.

The main ropeway components have been inspected and verified by random spot checks and it can be stated that these components represent the state of the art and best practice of aerial ropeways.

To ensure ongoing reliability of the cableway system, attention should be given to the following

- At various locations the track rope is showing signs of surface corrosion and dislocation of a few outer layers can be seen on the de-tensioned lengths on the anchor drums. Enhanced lubrication and relocation of the outer strands of the de-tensioned section of the rope is recommended.
- The structural adequacy of the suspension support for the CCTV camera at the towers to carry the loads from vibration, wind, self weight etc. should be confirmed.
- Parts of the brake discs of the winch drives of the rescue ropeway are exhibiting surface corrosion and require cleaning/protection.
- The braking concept e.g. under which conditions the modulated and non modulated emergency brakes are activated, needs to be described.

NP360 uses the Teichmann system for the transmission of safety related signals for the cableway through the haul rope and to monitor the position of the haul rope. The monitoring requires adequate insulation of the haul rope from earthed parts.

This system is both well known and well tried and is frequently and successfully being used in similar ropeway systems. Due to the length of Ngong Ping 360 and the numerous contact points between the haul rope and earth through rollers, carrier grips, deflection sheaves in the stations etc. the complete insulation of the entire haul rope is very difficult to achieve especially under damp and humid conditions. The measures currently being taken by the manufacturer to detect and eliminate possible earth leakage paths together with enhanced cleaning of contact points are considered appropriate.

We consider the Teichmann system in general as suitable for use in the installed ropeway system under the environmental conditions of Hong Kong. To enhance the reliability and efficiency of the system the insulation for the haul rope should continue to be improved as far as is possible.

The initial problems associated with the carrier storage system in the Tung Chung Terminal have already been identified by the manufacturer Leitner. Their proposed actions of certain component replacement improvements to both the control and diagnostics of the conveyance system and enhanced recovery procedures are considered suitable measures to increase reliability.

Hong Kong

6 Summary

The independent system review concludes that the components and ropeway systems of Ngong Ping 360 are considered essentially suitable to operate in the Hong Kong environment and represent the state of the art.

Both the reliability and availability of the cableway system, as compared to other similar installations, are considered to be high.

Based on our inspection on site we consider that the safety performance of the cableway is at the same high level as other comparable systems.

The ability to keep the current performance at this high level will be dependent on the continuing development of the capability and competence of the maintenance and operations staff. In order to ensure that this is achieved, it is recommended that the capability and competences of the maintenance and the operation staff continue to be enhanced.

Identified weak components of the cableway system should be replaced or improved as discussed with the manufacturer and operator and it is recommended that all identified actions be followed up in order to further enhance the system performance.

TÜV SÜD Hong Kong
Industry Service
Chief engineer

Seyfried

TÜV SÜD Industrie Service GmbH
Department of Ropeways
Chief engineer

Disl