ANALYSIS OF SHORELINE CHANGE:
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REPORT 4
NORTHERN GOLD COAST COASTAL IMAGING SYSTEM

by

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APPENDIX C – ICCE PAPER/PRESENTATION
Predicted and observed coastline changes at the Gold Coast artificial reef

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Abstract

One-line numerical modelling and three-dimensional scale physical model studies were completed to predict the extent of shoreline widening that could be anticipated at the Gold Coast in response to extensive sand nourishment (completed June 2000) and construction of a submerged reef structure (completion anticipated December, 2000). A coastal imaging system is currently being used to continuously monitor and quantify regional-scale coastal change. These data will provide the all-too-rare opportunity to compare and contrast predicted and prototype coastline adjustment to the implementation of major coastal engineering works.

Introduction

The Gold Coast attracts local, national and international visitors to the beaches of southern Queensland, Australia (Figure 1). The Surfers Paradise beachfront is a focus of the associated coastal development, supporting a range of accommodation, recreational and business infrastructure.

In 1997 the 'Northern Gold Coast Beach Protection Strategy' was initiated by Gold Coast City Council to maintain and enhance (i.e., widen) the beaches at Surfers Paradise (ICM, 1997). The major engineering included in the Strategy include an initial 1.2 Mm$^3$ of sand nourishment, ongoing sand nourishment of approximately 80,000 m$^3$ per year, and the construction of a submerged artificial reef structure. The initial phase of sand nourishment commenced in February 1999 and was completed in June 2000. Construction of the reef commenced in August 1999 and is due for completion by December 2000.

During the design phase, one-line numerical modelling and scale physical model studies were completed to predict the regional-scale coastline response to sand nourishment and the proposed reef. A video-based coastal imaging system has now been installed at the site, and is being used to monitor and quantify the predicted re-adjustment of the northern Gold Coast beaches.

This paper presents an overview of the physical and numerical model predictions of future coastal changes at the northern Gold Coast. This is followed by a more detailed description of the coastal imaging system presently being used to monitor and quantify the prototype changes, including a summary of the results of the first 12 months of regional-scale coastline monitoring.

Background

Beaches of the eastern Australia coast are typically high energy and dynamic. The Gold Coast beaches experience a net rate of northward littoral drift of approximately 500,000 m$^3$ per year and subjected to episodic storm erosion events. Historical and more recent coastal protection measures have included the

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Figure 1. Surfers Paradise, Australia.
construction of timber walls in the 1920’s and 1930’s, progressive construction of a continuous boulder wall along the entire northern Gold Coast beachfront, construction of the Nerang Seaway and sand-by-passing plant in the mid-1980’s, and periodic beach nourishment since the 1970’s.

Significant storms in May 1996 again highlighted the vulnerability of the northern Gold Coast beaches to severe storm erosion. Of particular concern is the area known as Narrowneck (refer Figure 1), where the buried rubble seawall that backs the beach is frequently exposed, and at such times there is no usable beach at high tide. This site was chosen to locate the new submerged reef structure presently under construction at the northern Gold Coast.

The principal function of the Gold Coast Reef is to provide a ‘control point’ to stabilise up-drift sand nourishment and to promote salient growth within its lee. Moderate beach widening is required as this will both increase beach amenity and provide a buffer to future storm erosion events. A pioneering feature of the reef is that its shape and configuration have been designed to also provide a world-class surfing break.

The Reef is constructed of approximately three hundred and eighty 150 – 300 tonne sand-filled geotextile containers stacked in a two and three layer configuration. The completed reef will extend approximately 350 m alongshore and 600 m offshore, in water depths ranging from 2 m to approximately 10.5 m. As noted earlier, construction of the reef is due for completion in late 2000.

Predictions of Coastline Changes

Prior to the commencement of the sand nourishment and reef construction engineering works, one-line numerical shoreline modelling (Turner et al., 1998a) and a 3-D scale physical model study (Turner et al., 1998b) were completed to assess the likely extent of beach widening that could be anticipated in the lee of the reef. Concurrent to these studies, the final design for the reef and detailed investigations of sedimentation around the reef were also completed (Black et al., 1998; Black, 1998).

Of primary concern was the possibility that the shoreline salient expected to develop in the lee of the reef, may over-widen and connect to the reef, to create a tombolo. On the high littoral drift coastline, the formation of a tombolo could be anticipated to cause extensive down-drift erosion, exacerbating rather than ameliorating the present erosion problems.

One-line numerical modelling

While the reef design was still at the conceptual stage, regional-scale one-line numerical modelling was completed for a 20 km long stretch of coastline, centered around the proposed location of the reef at Narrowneck. The GENESIS model (Hanson and Kraus, 1991) was used to undertake this initial assessment of the regional-scale impacts of nourishment and reef construction for a range of design scenarios.

The northern Gold Coast is a relatively complex section of coastline. The engineering features that were included in the numerical simulations included: nourishment along 2 km of the coastline; the submerged reef structure (modelled as an offshore breakwater exhibiting partial wave transmission); the buried seawall; the Nerang river entrance; the existing sand-bypassing plant at this river entrance; and possible back-passing of sediment from the river entrance to the beach immediately down-drift of the reef (Figure 2).

From the results of multiple simulations and sensitivity analyses, it was concluded that moderate beach widening (30 – 50 m) could be achieved within the lee of the reef, at the cost of relatively limited down-drift erosion, which could be effectively managed by annual nourishment. It was also concluded that

![Figure 2. Results of 1-line numerical model study.](image)
the salient that would form in the lee of the reef could be anticipated to assist in extending the design life of sand nourishment of the up-drift beaches (Turner et al., 1996a).

Three-dimensional scale physical model

A 1:50 scale physical model of the reef and 800 m of the adjacent coastline was constructed to further investigate the anticipated extent of shoreline adjustment in the lee and immediate vicinity of the reef. A hybrid fixed-bed/sediment-tracer technique was employed, using a light-weight pvc material to examine the new equilibrium shore alignment (Turner et al., 1999; Turner et al., in press).

Following extensive model testing, it was concluded that the formation of a tombolo was not anticipated due to the high degree of wave energy penetration into the lee of the reef. The high transmission of the submerged structure, and strong diffraction and refraction around both the northern and southern flanks of the structure, account for such high penetration of wave energy. Current patterns that developed around the model reef also assisted to limit the potential for over-widening of the beach.

Coastal Imaging System

In July 1999 an ARGUS coastal imaging system (Holman et al., 1993) comprising four individual cameras was installed at the northern Gold Coast. This leading-edge technology was selected as it could meet the necessary criteria of providing quantitative, continuous and long-term monitoring of the predicted regional-scale adjustment of northern Gold Coast beaches. This is the first time that coastal imaging has been used in Australia to quantify the regional-scale response to major coastal engineering works, and it is fitting that the technology should be used in conjunction with the implementation of the innovative engineering works underway at the northern Gold Coast. The coastal imaging system installed at the northern Gold Coast became fully operational on 1st August 1999. This timing coincided with the commencement of the reef construction works. Beach nourishment commenced approximately six months prior to the installation of the coastal imaging system, in February 1999.

Image Types

The coastal imaging system installed at the northern Gold Coast is presently configured to collect three different types of images. A fourth image type is also created by automated post-processing of images at the completion of each day. Images are collected every daylight hour. The image collection procedure is fully automated and controlled by an SGI workstation at the remote site, which also manages the automated transfer of the images to the Water Research Laboratory in Sydney (located some 1000 km south of the Gold Coast) for archiving, analysis and public distribution via the world-wide web. The growing archive of all images collected at the northern Gold Coast are available for public viewing (and down-load) at:

http://www.wrl.unsw.edu.au/coastal imaging/

Snap-shot images are the simplest image type collected by the Gold Coast coastal imaging system (Figure 3a). These are the same images that would be obtain by a conventional digital camera. Snap-shot images provide simple documentation of the general characteristics of the beach, but they are not so useful for obtaining quantitative information.

Figure 3a. ‘Snap-shot’ image.

Time-exposure images are a much more useful image type created by the coastal imaging system. Time-exposure images are created by the ‘averaging’ of 600 individual snap-shot images collected at the rate of 1 picture every second, for a period of 10 minutes each hour. A lot of quantitative information can be obtained from these images. Time exposures of the shore break and nearshore
wave field have the effect of averaging out the natural variations of breaking waves, to reveal smooth areas of white (Figure 3b), which have been shown to provide an excellent indicator of the shoreline and nearshore bars (Lippmann and Holman, 1989). In this manner, a quantitative 'map' of the underlying beach morphology can be obtained.

*Variance images* are also created at the same time that the time-exposure images are being collected. Whereas the time-exposure is an 'average' of many individual snap-shot images, the corresponding variance image displays the variance of light intensity during the same 10 minute time period. Variance images can assist to help identify regions which are changing in time, from those which may be bright, but unchanging. For example, a white sandy beach will appear bright on both snap-shot and time-exposure images, but dark in variance images, whereas zones of wave breaking will appear as bright regions within the variance image (Figure 3c).

*Day time-exposure Images* are the fourth image type routinely obtained from the coastal imaging system installed at the northern Gold Coast. It is created at the end of each day of image collection, by the averaging of all hourly time-exposure images collected that day. This has the effect of 'smoothing' the influence of tides, and for some conditions may enhance the visibility of the shore break and bar features in the nearshore.

**Image Processing**

The key feature of coastal imaging technology that distinguishes it from conventional webcam systems is the ability to extract quantitative information from the images. This is achieved through the solution of a set of camera model parameters (Holland et al, 1997) to extract 3-D real-world position from 2-D image coordinates, and the application of image processing techniques to identify, enhance and manipulate the image features of interest.

Image merging is achieved by the solution of camera model parameters for individual cameras, then the boundaries of each image are matched to produce a single composite image. Image rectification is then undertaken, whereby the dimensions of the merged image are corrected so that each pixel represents the same area on the ground, irrespective of how close or far it may from the camera position. (In contrast, for an unrectified image the area represented by each pixel increases with increasing distance from the camera).

Image rectification is achieved by using the calculated camera model parameters to fit an image to a regular grid that defines longshore and cross-shore distance.

The rectification of merged images produces a 'plan view' of the area covered by all four cameras. This is illustrated in Figure 4. This example of a merged and rectified image created from four oblique images is analogous to a montage of distortion-corrected photographs taken from an aeroplane flying directly overhead the northern Gold Coast. The pixel resolution of the merged/rectified images created at the Gold Coast is 5m.

Note that the black triangular region in the middle of this plan view image is the region within the otherwise 180° field of view that is not covered by the four-camera system. To include this region in the merged/rectified image would require a fifth camera, which budget constraints could not justify. This missing region is relatively unimportant however, as it occurs seaward of the surfzone.

**Automated Shoreline Detection**

To map the position of the shoreline and its changing location through time, a rigorous image analysis methodology was developed to enable the extraction of this information from the ARGIS images. A new shoreline technique was developed, utilising the full colour information available at the northern Gold Coast site. This technique, developed specifically to analyse the images from the northern Gold Coast coastal imaging system, utilises the different reflectance properties of 'wet' and 'dry' regions within the images.

![Figure 4. Plan view (merged/rectified) time-exposure image](image-url)
A full description of the shoreline detection procedure can be found in Turner and Leyden (2000). Briefly, the divergence of RGB (Red-Green-Blue) components within each image is exploited to define a ‘shoreline indicator’. By using an objective edge detection method to pick the cross-shore location where the individual colour components diverge, and by repeating this procedure at all positions alongshore, the location of the shoreline indicator along the entire length of beach is defined (Figure 5). Following this approach, an automated software tool was written to implement the full-colour shoreline detection method. This technique is presently used to map the shoreline at weekly (nominal 7 day) intervals.

**Analysis of Shoreline Change: August 1999 – July 2000**

The growing database of weekly shoreline positions are subjected to a range of standard statistical analyses, as illustrated below.

The upper panel of Figure 6 shows beach width (relative to the vegetated dune line) for the 12 month monitoring period August 1999 to July 2000, along the entire 4500 m study region of the northern Gold Coast. The limited number of discontinuous shorelines in the central region are due to the narrow beach in this region early during the monitoring period. In the lower panel of this figure the location of the reef construction site is indicated.

To date, the dominant feature of coastline change observed at the northern Gold Coast is extensive beach widening due to the initial phase of sand nourishment, centered around 1000 m south of the reef construction site at Narrowneck (which by coincidence is also directly seaward of the location of the cameras). Over this initial 12 month monitoring period the beach varied in width by over 150 m, with beach width changes in excess of 100 m measured in the central region of the study area, while total beach width changes of 50 m were more typical in the regions to the north and south. Salient growth in the lee of the partially constructed reef is not yet apparent.

**Figure 6.** Weekly shorelines: August 1999 – July 2000 [reef indicated].

Figure 7 summarises the mean rate of beach erosion/accretion over this same 12 month period. This was calculated by determining the linear best-fit to weekly shoreline positions measured at 25 m intervals along the 4500 m study area. In the left panel the six nourishment areas are indicated. When interpreting this
figure, it is important to recognise that nourishment of deposition areas A1, A2 and A3 was largely completed prior to the commencement of the monitoring program.

A general 12 month net accretionary trend was measured within the entire 4500 m study region, with the exception of the beach south of deposition area A6 (where no nourishment occurred) and for the region centered around nourishment areas A2 and A3 (i.e., Narrowneck) where nourishment was largely completed immediately prior to the commencement of the monitoring program. The reduced net accretion rate of approximately 0.1 - 0.4 m per week in this region, compared to up to 1.5 m per week in the more recently nourished deposition areas A4 and A5, is interpreted to indicate an initial phase of shoreline recession following the completion of beach nourishment works, as sediment was redistributed across the nearshore by the action of waves, with the beach returning towards an equilibrium profile form. It is presumed this same initial erosional trend will also be observed at the more southern areas.

Conclusions

Over the coming years the coastal imaging system installed at the Gold Coast will provide the all-to-rare opportunity to compare predicted and observed prototype coastline changes, enabling a quantitative assessment of the strengths and weaknesses of available coastal engineering predictive tools. During the initial 12 month construction monitoring period, the rapid adjustment of the beach to the sand nourishment works has been quantified, including an early erosional phase, immediately following the completion of nourishment works at staged nourishment areas alongshore. With the initial phase of major nourishment now completed, the focus of the next 12 months monitoring will be to establish the extent and rate of anticipated salient growth in the lee of the submerged reef structure.

References


The Application of Video Imaging at the Gold Coast to Quantify Beach Response to Sand Nourishment and Construction of an Artificial Reef

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Abstract

A video-based coastal imaging system is being used at the northern Gold Coast to monitor and quantify the regional-scale coastal response to sand nourishment and construction of the world-first Gold Coast artificial reef. This automated monitoring system is used to obtain hourly images from four cameras of a 4.5 km length of the coast. Sophisticated digital image processing techniques are then applied to extract a range of information from the growing image database. Analysis includes the quantification of changing shoreline position (and hence beach width), the measurement of three-dimensional inter-tidal morphology, and the comparison of wave breaking frequency at the reef and adjacent nearshore bars.

1. INTRODUCTION

In July 1999 an ARGUS coastal imaging system (Holman et al., 1993) was installed at the northern Gold Coast. This leading-edge technology was selected as it could meet the objectives of providing quantitative, continuous and long-term monitoring of the predicted regional-scale adjustment (Turner et al., 1998; Turner et al., 2000; Turner et al., in press) of the northern Gold Coast beaches.

The principal objective of the system is to monitor and quantify for Gold Coast City Council the changing shoreline alignment, with particular focus on the reef site at Narrowneck and the Surfers Paradise beachfront (refer Figure 1). However, the growing database of geo-referenced digital images has proved to be a valuable resource, that is also providing the basis for a number of complementary investigations. Following a description of the coastal engineering works recently completed at the northern Gold Coast and a brief introduction to coastal imaging, this paper illustrates some of the capabilities of the system, including: the analysis of shoreline changes, the extraction of three-dimensional inter-tidal profile information from the images, and observations of wave breaking frequency at the reef.

Figure 1: Location

2. BACKGROUND

Gold Coast beaches are typical of the eastern Australian coast, being energetic and dynamic. Gold Coast beaches experience a net rate of northward littoral drift of approximately 500,000 m³ per year and are subject to episodic storm erosion. Historically, timbers walls were
constructed to provide beach protection and a continuous boulder wall was progressively constructed along the entire Gold Coast beach front. Periodic beach nourishment has taken place since the 1970’s, and the Nerang Seaway and associated sand by-passing plant were constructed in the mid-1980’s.

In 1997 the ‘Northern Gold Coast Beach Protection Strategy’ was initiated by Gold Coast City Council to maintain and enhance (i.e., widen) the beaches at Surfers Paradise (Boak et al., 2000). The major engineering works included in the Strategy included an initial 1.2 Mm³ of sand nourishment and the construction at Narrowneck of a submerged artificial reef structure to provide a coastal ‘control point’ and to enhance surfing opportunities at the northern Gold Coast. The sand nourishment was completed in June 2000 and reef construction ceased in December 2000.

3. WHAT IS COASTAL IMAGING?

The ARGUS coastal imaging system currently operating at the northern Gold Coast consists of four cameras that together provide 180° coverage of the coastline (Figure 2). The system is installed at an elevation of 100 m above sea level, located in the services area of a high-rise apartment building. Hourly image collection is fully automated and controlled by an SGI workstation at the site, that also manages the automated transfer of images to the Water Research Laboratory in Sydney for archiving, analysis and public distribution via the world-wide web. The growing database of images collected at the northern Gold Coast are available for public viewing (and down-load) at:

→ http://www.wrl.unsw.edu.au/coastalimaging/

At the core of coastal imaging is the ability to extract quantitative information from a time-series of high quality digital images. This is achieved by the careful calibration of the cameras and the derivation of a set of mathematical equations that are used to inter-convert between two-dimensional image co-ordinates and three-dimensional ground (i.e., ‘real-world’) coordinates. Sophisticated image processing techniques are then used to extract and quantify information contained with the images.

4. ANALYSIS

4.1. Shoreline Changes

As noted earlier, the principal objective of the coastal imaging system at the northern Gold Coast is to monitor regional-scale shoreline changes and beach width. This analysis is undertaken on a six-monthly basis, and at the time of writing analysis for the 18 month period August 1999 to January 2001 (total 78 weeks) is available.

Shorelines are mapped at weekly intervals using a shoreline detection technique developed at the Water Research Laboratory. This technique is
based upon the separation of the RGB (red-green-blue) information that comprise each image, and identifies the shoreline by the different reflectance properties of ‘wet’ and ‘dry’ regions of the image (Turner et al., 2000).

seasonal shoreline response, which can be examined further once the influence of the nourishment has equilibrated. Other analyses that are performed of these shoreline data include the assessment of beach width variability, erosion-accretion rates and the identification of differing beach response up-drift, down-drift and in the lee of the reef site at Narrowneck.

4.2. 3-D Inter-tidal Profile Analysis

A new image analysis technique has been applied to the images obtained from the northern Gold Coast coastal imaging system that enables three-dimensional inter-tidal profile information to be extracted from the two-dimensional images. Briefly, the technique involves mapping multiple waterlines during a tidal cycle. The horizontal location (x,y) of these waterlines is determined from ARGUS images, whereas the associated vertical elevation (z) is obtained from an empirical approach which accounts for the tide, wave set-up, surf beat and swash (Aarninkhof et al., 2000).

Figure 3: Shoreline Analysis

The resulting time-series of weekly shorelines can be analysed in a number of different ways to assess regional-scale beach changes. One example is illustrated in Figure 3. In this figure the beach width at five sites located 500 m, 1000 m, 1500 m, 2000 m and 2500 m north of the cameras are plotted. For reference, Narrowneck is located approximately 1 km north of the cameras (y = 1000 m) and wave breaking on the reef is visible in the merged/rectified time-exposure image shown. The weekly beach width at these five sites (measured relative to the dune vegetation line) shows that a generally accretionary trend occurred during the 18 month period August 1999 – January 2001, as would be expected due to the sand nourishment operations that were underway during the majority of this time. These data also suggest a

Figure 4: 3-D inter-tidal profile mapping
An example of the results of inter-tidal profile mapping is shown in Figure 4. In the upper image two 'proto-salient' features are visible at Narrowneck that were observed in the latter part of 2000. In the lower panel, the expression of these morphological features within the inter-tidal profile is clearly evident. This technique for mapping three-dimensional morphology clearly has wide application, as virtually continuous 'survey' data can be obtained under all conditions, without the need to deploy equipment or personnel to the site.

At the Gold Coast, mapping of the inter-tidal profile has been undertaken on a monthly basis. Again, the results can be used to perform a range of analyses. One example is the calculation of changes in the inter-tidal profile since sand nourishment was completed in June 2000, to assess the beach changes in the lee of the reef structure. Figure 5 shows monthly beach profile changes (i.e., accretion/erosion) for the period December 2000 to April 2001, along a 1000 m length of the beach, relative to the profile measured in July 2000. Reef construction ceased in December 2000, and so this figure shows the initial beach changes that occurred in the lee of the completed reef. In general, it can be seen that an erosional trend persisted, with progressive erosion moving in a northerly direction alongshore. A possible 'signature' of the reef appears in the centre of this 1000 m region of the beach, where the rate of more general erosion appears to have been somewhat retarded.

Figure 5: Inter-tidal profile changes (relative to July 2000 – i.e., completion of sand nourishment)
4.3. Wave Breaking at Reef

Wave breaking on the reef at Narrowneck is now commonly visible in images obtained by the coastal imaging system. Reef construction took place during 2000 through two periods: January – May and September – December, with the crest level raised as additional geocontainers were placed at the site. The upper image in Figure 5 shows a single-camera, time-exposure image obtained at 6:00 pm in the evening of 31st December 2000, and the lower picture shows the corresponding merged/rectified image created from all four camera images at this time.

![Wave Breaking at Reef](image)

**Figure 5: Wave Breaking at Reef**

Referring to Figure 5, wave breaking seawards of the inner bar in the distinctive shape of the reef is discernable. Breaking waves across the two halves of the reef are clearly visible, with these two linear regions of wave breaking separated by the deeper paddling channel that bisects the reef structure.

At the time of writing, the results of analysis are available of all daylight hourly images for the period 1 January to 31 December 2000, to quantify the frequency of wave breaking across the reef, as well as wave breaking observed on the adjacent (undisturbed) bar. Figure 6 summarises the results of this analysis. In total, approximately 4,700 images were examined.

The lower panel of this figure shows the count of hourly daylight images in which waves were observed to break on the reef, and the corresponding number of images in which wave breaking on the adjacent storm bar was also visible. To assist the interpretation of this information, in the upper panel of this figure the percentage occurrence of wave breaking at the reef only (i.e., no visible breaking on the adjacent bar) is plotted. A polynomial fit to these data is included, to highlight the dominant trend.

It can be seen from this analysis that early in 2000 wave breaking at the reef only was occurring approximately 20% of the time, indicating that 80% of the time waves were breaking on the adjacent bar at the same time as they were observed to break on the reef. However, the increasing influence of the reef through the year can be seen, up to the final three months of 2000 when 80% - 100% of the time wave breaking at the reef was occurring in the absence of breaking on the adjacent bar.

![Wave Breaking Analysis](image)

**Figure 6: Analysis of the Occurrence of Wave Breaking at the Reef**

This initial analysis does not consider the quality of the breaking waves for surfing (e.g., peel angle and breaker type), nor the coincidence of breaking waves with favorable winds for surfing, but simply the occurrence of additional breaking waves due to the reef. Wave breaking at the reef only is of course partially a function of the prevailing wave climate in any particular month. However, it may be concluded from these initial results that the reef has achieved the objective of increasing potential surfing opportunities at Narrownack.
5. Discussion and Conclusions

The installation of a leading-edge ARGUS coastal imaging system at the Gold Coast is providing the unprecedented opportunity to carry out post-construction monitoring of the major coastal protection works recently completed at the northern Gold Coast. Examples are all too rare in the professional literature of quantitative studies undertaken over periods of several years to measure the success with which design and management objectives have been met. As well as providing a rigorous and comprehensive management and engineering tool to assess the regional-scale adjustment of northern Gold Coast beaches to sand nourishment and construction of the submerged reef structure, the image database is now providing the foundation for a growing number of spin-off research investigations. Yet again, this demonstrates the value and importance of establishing and maintaining longer-term coastal data collection programs for the Australian coastline.

6. ACKNOWLEDGMENTS

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7. REFERENCES

